

POTASSIUM MOVEMENT IN LAKELAND FINE SAND AND EFFECTS
ON YIELD AND COMPOSITION OF FLUE-CURED TOBACCO
(Nicotiana tabacum L.)

By

GENARO ORZALES SAN VALENTIN

A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL
OF THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1974

TO MY MOTHER

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to all the members of his supervisory committee, Dr. W. K. Robertson, Mr. H. W. Lundy, Dr. W. S. Brey, Jr., Dr. L. W. Zelazny, Dr. N. Gammon, Jr., and Dr. R. S. Mansell.

The author is deeply indebted to Dr. W. K. Robertson for his supervision and guidance in the research and for his encouragement and inspiration. Sincere appreciation is expressed to Mr. H. W. Lundy for his major contribution in the planning and conduct of the research and for providing financial assistance and to Dr. N. Gammon, Jr. for his valuable criticisms and suggestions in the preparation of the manuscript.

Appreciation is expressed to Dr. L. C. Hammond for his assistance and guidance in the work pertaining to soil physics and to Mr. R. E. Jessup for analyzing samples in the soil physics laboratory. Gratitude is expressed to Dr. R. S. Mansell for his valuable suggestions in the conduct of the laboratory experiments and for providing the equipment for the miscible displacement study.

The author also expresses his gratitude to Dr. L. Ibe, Dr. I. G. Valencia, Dr. I. Santos, and Mr. A. de Guzman of the Philippine Atomic Energy Commission; and to Dr. C. F. Eno of the Department of Soil Science, University of Florida for the contributions they have made in making the author's graduate studies at the University of Florida possible.

Finally, the author wishes to express his gratitude and appreciation to Mrs. Paulita de los Reyes Puzon for typing the manuscript and to all the people who have provided a familiar atmosphere during his extended stay in the United States.

TABLE OF CONTENTS

| | Page |
|------------------------------|------|
| ACKNOWLEDGEMENTS..... | iii |
| LIST OF TABLES..... | v |
| LIST OF FIGURES..... | ix |
| ABSTRACT..... | x |
| INTRODUCTION..... | 1 |
| LITERATURE REVIEW..... | 3 |
| MATERIALS AND METHODS..... | 15 |
| Field Experiments..... | 15 |
| Laboratory Experiments..... | 24 |
| RESULTS AND DISCUSSION..... | 31 |
| Field Experiments..... | 31 |
| Laboratory Experiments..... | 90 |
| SUMMARY AND CONCLUSIONS..... | 112 |
| LITERATURE CITED..... | 115 |
| BIOGRAPHICAL SKETCH..... | 120 |

LIST OF TABLES

| Table | Page |
|--|------|
| 1. Treatments in 1972 experiment on flue-cured tobacco..... | 16 |
| 2. Treatments in 1973 field experiment on flue-cured tobacco..... | 17 |
| 3. Mean yield of flue-cured tobacco in 1972 experiment..... | 32 |
| 4. Analysis of variance for yields of flue-cured tobacco from 1972 experiment..... | 33 |
| 5. Overall analysis of variance for yields, K uptake, and K, total alkaloid (TA), total reducing sugar (RS) contents of leaves in 1972 field experiment..... | 34 |
| 6. Regression equations for yield and K uptake based on rate..... | 36 |
| 7. Mean K contents of leaves in 1972 experiment..... | 37 |
| 8. Analysis of variance for K contents of the leaves in 1972 experiment..... | 38 |
| 9. Regression equations for K contents of the leaves based on rate..... | 39 |
| 10. Results from Duncan's multiple range test for treatment means in 1972 experiment..... | 40 |
| 11. Mean total alkaloid (TA) and total reducing sugar (RS) contents of tobacco leaves from 1972 experiment..... | 42 |
| 12. Analysis of variance for total alkaloid and reducing sugar contents of tobacco leaves from 1972 experiment..... | 43 |
| 13. Regression equations for total alkaloid (TA) and reducing sugar (RS) contents of tobacco leaves based on rate..... | 44 |
| 14. Treatment x rate interaction means for total alkaloid contents of tobacco leaves in 1972 experiment..... | 46 |
| 15. Prices of flue-cured tobacco in 1972 experiment..... | 47 |

| Table | Page |
|--|------|
| 16. Analysis of variance for price of flue-cured tobacco data in 1972 experiment..... | 48 |
| 17. Effect of treatment on K contents of soil in 1972 field experiment..... | 49 |
| 18. Treatment x depth interaction means for Ca contents of the soil..... | 50 |
| 19. Treatment x depth interaction means for Mg contents of the soil in 1972 experiment..... | 51 |
| 20. Analysis of variance for K, Ca, and Mg contents of the soil in 1972 experiment..... | 52 |
| 21. Rainfall data in 1972 at the experimental site..... | 55 |
| 22. Soil water tension at various depths, before and after rainfall or irrigation during the five-week soil sampling period in 1972..... | 56 |
| 23. Mean yield of flue-cured tobacco in 1973 experiment..... | 59 |
| 24. Analysis of variance for yields of flue-cured tobacco from 1973 experiment..... | 60 |
| 25. Overall analysis of variance for yields, K uptakes, and K, total alkaloid (TA), and total reducing sugar (RS) contents of leaves in 1973 experiment..... | 61 |
| 26. Results of Duncan's multiple range test on treatment means for yield response in 1973 experiment..... | 63 |
| 27. Mean K contents of leaves in 1973 experiment..... | 64 |
| 28. Analysis of variance for K contents and total uptakes in 1973 experiment..... | 65 |
| 29. Treatment x rate interaction means and regression equations for K contents..... | 66 |
| 30. Results of Duncan's multiple range test on treatment means for responses with treatment x rate interaction effects..... | 67 |

| Table | Page |
|---|------|
| 31. Results of Duncan's multiple range test on treatment means for K content and K uptake response in 1973 experiment..... | 70 |
| 32. Mean total alkaloid (TA) and total reducing sugar (RS) contents of flue-cured tobacco in 1973 experiment..... | 71 |
| 33. Analysis of variance for total alkaloid and total reducing sugar contents of tobacco leaves from 1973 experiment..... | 72 |
| 34. Results of Duncan's multiple range test on treatment means for total alkaloid and reducing sugar contents of the leaves..... | 73 |
| 35. Prices corresponding to the grades of flue-cured tobacco in 1973 experiment..... | 75 |
| 36. Analysis of variance for price of flue-cured tobacco data in 1973 experiment..... | 76 |
| 37. Results of Duncan's multiple range test on treatment means for price of flue-cured tobacco and total value in 1973 experiment..... | 77 |
| 38. Effect of treatments on K contents of soil in 1973 field experiment..... | 78 |
| 39. Analysis of variance on K contents of the soil..... | 80 |
| 40. Results of Duncan's multiple range test for sampling x treatment and sampling x depth interaction effects on K contents of the soil..... | 81 |
| 41. Results of Duncan's multiple range test for treatment x depth interaction effects on K content of the soil in fourth sampling..... | 82 |
| 42. Rainfall data in 1973 at the experimental site..... | 83 |
| 43. Soil water tension (h), water content (θ), and K content at different depths before and after the first application of water..... | 85 |
| 44. Soil water tension (h), water content (θ), and K content at different depths before and after the second application of water..... | 87 |

| Table | Page |
|--|------|
| 45. Soil water tension (h), water content (θ), and movement of K, Ca, and Mg from soluble (S) and slowly soluble (SS) fertilizer (7-6-17.5) following application of 15 cm of water at 2.5 cm/hr..... | 88 |
| 46. Some physical and chemical properties of Lakeland fine sand..... | 91 |
| 47. Extractable K, Ca, Mg, and Al with \underline{N} NH_4OAc (pH 4.8 and pH 7)..... | 92 |
| 48. Water retention characteristics of Lakeland fine sand..... | 93 |
| 49. Hydraulic conductivity of the soil at different suctions... | 94 |
| 50. Quantity-intensity (Q/I) relation of Lakeland fine sand.... | 95 |
| 51. Soil water tension (h) and water content (θ) before (t=0) and after the first application of 2.5 cm of water at the rate of 2.5 cm/hr..... | 97 |
| 52. Soil water tension (h) and water content (θ) before and at different times (in hours) after the second application of 2.5 cm of water at the rate of 2.5 cm/hr..... | 98 |
| 53. Soil water tension (h) and water content (θ) before and at different times (in hours) after the third application of 2.5 cm of water at the rate of 2.5 cm/hr..... | 99 |
| 54. Soil water tension (h) and water content (θ) before and 15 hr after the fourth application of 2.5 cm of water at the rate of 2.5 cm/hr..... | 100 |
| 55. Soil water tension (h), water content (θ) and K, Ca, and Mg contents of the soil solution at different depths before and 9.5 hr after 15 cm of continuous application of water.. | 103 |

LIST OF FIGURES

| Figure | Page |
|--|------|
| 1. Soil solution sampling apparatus used in the field experiment on K leaching..... | 21 |
| 2. Soil solution sampling apparatus used in the laboratory experiment on K leaching..... | 26 |
| 3. Apparatus used in the miscible displacement study under unsaturated condition..... | 28 |
| 4. Potassium concentration in soil solution at different depths 15 hr after the first, second, third, and fourth application of 2.5 cm of water at 2.5 cm/hr rate..... | 101 |
| 5. Breakthrough curves of K (●) and Cl ⁻ (○) under saturated condition at flow velocity of 18 cm/hr... | 107 |
| 6. Breakthrough curves of K (●) and Cl ⁻ (○) under saturated condition at flow velocity of 22 cm/hr... | 108 |
| 7. Breakthrough curves of K (●) and Cl ⁻ (○) under saturated condition at flow velocity of 69 cm/hr... | 109 |
| 8. Breakthrough curves of K (●) and Cl ⁻ (○) under unsaturated condition..... | 110 |

Abstract of Dissertation Presented to the
Graduate Council of the University of Florida in Partial Fulfillment
of the Requirements for the Degree of Doctor of Philosophy

POTASSIUM MOVEMENT IN LAKELAND FINE SAND AND EFFECTS
ON YIELD AND COMPOSITION OF FLUE-CURED TOBACCO
(Nicotiana tabacum L.)

By

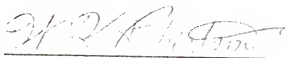
Genaro Orzaes San Valentin

June, 1974

Chairman: William K. Robertson

Major Department: Soil Science

Potassium (K) movement in Lakeland fine sand was studied in the field with and without indicator crop, and in the laboratory using reconstituted soil columns. To determine effects of K movement on yield and composition of flue-cured tobacco (Nicotiana tabacum L.), different slowly soluble and soluble fertilizers containing K were tested. Although there were observed differences in yields of flue-cured tobacco and in K, total alkaloid, and total reducing sugar contents of the tobacco leaves from two years' field experiments, the differences did not indicate any advantage of the slowly soluble K fertilizers over the tobacco-grade fertilizer applied split. Results from field and laboratory experiments showed extent of K movement as affected by amount of water applied to the soil. Results from miscible displacement studies conducted in the laboratory supported the observation from both field and laboratory experiments that K was lagging behind the water moving downward.


Chairman

INTRODUCTION

Common sources of potassium (K) applied to agricultural crops are very soluble in water. Their use, particularly at high rates in combination with other fertilizers, have fostered problems associated with high salt concentration in the plant-root environment. In sandy soils, during periods of heavy rainfall, leaching may reduce K concentration to a level of deficiency. To alleviate high salt concentration and to minimize leaching losses, split applications of the fertilizer K are recommended and additional applications are suggested after unusually heavy rains. Such is the case for flue-cured tobacco (Nicotiana tabacum L.) production in Florida. Slowly soluble sources of K, which are less susceptible to leaching, are now available commercially and others are currently undergoing testing for their effectiveness. More products will probably become available commercially in the near future. These sources may prove to be effective in satisfying the crop's requirement for K, possibly in only one application and at a relatively low rate.

Flue-cured tobacco is an important cash crop in Florida. The market value of the crop depends not only on the total yield but also on the grade of the cured tobacco leaves as determined by federal tobacco inspectors. The tobacco grade is an index of the quality of cured leaves which is related to the chemical composition. Yield and quality are markedly influenced by climate and cultural practices. Soil fertilizer management is therefore a very important aspect of the cultural practices in commercial tobacco farms and tobacco growers are very much aware of this. For example, farmers apply excessive amounts of fertilizers to

ensure the crop of an available nutrient supply under conditions of high rainfall. If excess fertilizer is not leached by rainfall it may be leached by irrigation.

There has been much work done on nutrient movement in the soil under field, laboratory, and greenhouse conditions. Nitrogen (N) and phosphorus (P) have received most attention because of their importance in environmental pollution. Movement of K is of more concern relative to its availability to plants since it is not considered a pollution hazard. Studies of K movement in the soil are more valuable if carried out under field conditions with a growing crop since it allows evaluation of factors affecting K movement in relation to plant uptake and other growth parameters. Since tobacco takes up K in large quantities, it is a good indicator crop to study K movement.

The objectives of this research were to study the effect of soluble and slowly soluble K fertilizers on yield, composition, and quality of flue-cured tobacco and to determine the effect of rainfall and irrigation on the movement of K from these fertilizers in Lakeland fine sand. These objectives were determined in the field and laboratory.

LITERATURE REVIEW

Chemically, flue-cured tobacco consists mainly of organic substances such as alkaloids, organic acids and bases, carbohydrates, essential oils, resins, and other nitrogenous constituents (Hawks, 1970). Various analyses are made to predict quality of flue-cured tobacco. The most common analyses are: total N, protein N, α -amino N, nicotine, reducing sugars, starch, non-volatile acids, and petroleum ether extractables. The quantity as well as the balance of these constituents determine the quality of tobacco (Hawks, 1970).

The flavor and pleasing quality of the taste of smoke is directly related to the content of the nitrogenous constituents (Hawks, 1970). A high total N content produces a strong or more pungent taste. If the content of nitrogenous constituents is low, the taste is flat and unpleasing. High content of oxalates and insoluble carbohydrates impart a bitter and irritating taste to the smoke. The lower the α -amino N content of tobacco the more aromatic and pleasing the smoke will be.

A good quality tobacco is also associated with a high sugar content if the N balance is maintained. Sugar content of the leaf is negatively correlated with N content (Woltz, Reid, and Colwell; 1948).

A high K content of flue-cured tobacco has been used as a measure of quality (Hawks, 1970). The quality factors related to K content are concerned with the physical appearance which determines the grade of the tobacco leaves in the market. A high K content is believed to produce deeper orange color of leaves. Hawks, Terry, and Collins (1973) observed no significant response of yield and quality of flue-cured tobacco to

rates of K fertilization in some North Carolina soils.

Nelson and McEvoy (1945) as cited by McCants and Woltz (1967) obtained evidences suggesting that tobacco plants can build up a reserve of K in the early stages of growth sufficient to sustain the later phase of development. Deficiency symptoms occurred when K supply was eliminated four weeks prior to harvesting. On the other hand, when the K supply was maintained until two weeks prior to harvesting, the reserve in the plant sustained the remaining development without additional absorption.

The availability of K from some slowly soluble K fertilizers to flue-cured tobacco was studied in a field experiment by San Valentin, Robertson, and Lundy (1971). The results showed that lower rates of Osmocote 12-0-34 (12% N, 0% P, 34% K) and sulfur-coated K_2SO_4 (SCK) produced yields and value of flue-cured tobacco that were not significantly different from those using higher rates of commercial 4-3.5-10 and granular K_2SO_4 , which are both soluble sources of K. The total K uptake in the harvested leaves followed the order: Osmocote 12-0-34 > commercial 4-3.5-10 (applied split) > SCK (26% coating) > SCK (21% coating) > $K_2SO_4 \cdot MgSO_4$ (K-Mag) > granular K_2SO_4 .

The role of K in the plant is not clearly understood unlike other nutrients because studies on K are confounded with difficulties associated with its being soluble in the cell sap and not being synthesized with any specific compound in the plant. A review of literature has been written on the role of K in photosynthesis and respiration by Jackson and Volk (1968), on carbohydrate metabolism and translocation by Liebhardt (1968), on effects of K on organic acid and nonprotein N content by Teel (1968), and on effects of K on enzymes by Wilson and Evans (1968). One of the most recent findings on the role of K in photosynthesis is on the closing

and opening of the stomata which has been found to be dependent on the movement of K in and out of the guard cells (Jackson and Volk, 1968). On carbohydrate metabolism, K has been observed to reduce condensation of simple carbohydrates to more complex forms (Liebhardt, 1968). Numerous enzyme systems in the plant require K in their reactions and many of these enzymes are involved in protein or N metabolism (Wilson and Evans, 1968).

The K requirement of crops varies (Fried and Broeshart, 1967). Tubers and root crops, tobacco, pineapple, and sugar cane remove large amounts of K usually more than 200 kg K/ha. Vegetables such as tomatoes, cauliflower, and cabbage also remove large amounts of K from soil. Grain crops and legumes remove less, the former from 67 to 78 kg K/ha and the latter from 45 to 123 kg K/ha.

Nutrient movement from the soil to the plant may be described by three mechanisms: 1) movement through the soil to the root surface, 2) movement from the root surface to the interior of the root, and 3) movement from root to various parts of the plant. Nutrients may reach the root surface by root interception, mass-flow, and diffusion (Barber, 1962 and Barber, Walker, and Vasey, 1963). Movement by mass-flow is related to water movement along the transpiration stream. As soil water around the root becomes depleted, a hydraulic gradient develops causing water movement from regions of greater water content to regions immediately surrounding the roots. The significance of mass-flow depends on the volume of water absorbed by the plant and the concentration of the nutrient in the soil solution. Movement by diffusion is over much shorter distances than mass-flow (Drew, Vaidyanathan, and Nye; 1967).

Among the factors limiting nutrient uptake by plant roots are the amount and distribution of roots in the soil. Roots come in contact

with the nutrients as they grow and the maximum amount of nutrients which can be contacted depends on the volume of roots formed and the concentration of the nutrient in that particular volume of soil where the roots are growing (Barber, Walker, and Vasey; 1963).

Howard and Adams (1965) showed that cotton root extension in the soil is related to the ratio of Ca to total cations. When Ca content was less than 20% of total cations, root growth decreased sharply. Adams and Lund (1966) showed restriction of primary root growth by Al in three acid soils of widely different properties. A relationship was observed between Al concentration of soil solution and root growth but not with exchangeable Al.

The amount of K absorbed by roots is determined by concentration or more appropriately the activity of K in the bulk soil solution which in turn is dependent on the electrochemical potential of K and other ions surrounding the exchange complex forming the diffuse double layer. The electrochemical potential of ions in the exchange phase can not be measured, nor it is directly proportional to the concentration of ions in the equilibrium soil solution (Beckett, 1967). This problem is avoided by measuring the differences between the electrochemical potential of two ions which is constant in all parts of the solution, double layer, or solid phase at equilibrium (Beckett, 1972). At equilibrium, the activity ratio of K to Ca in soil solution, a_K/a_{Ca} , is proportional to their difference in electrochemical potential. The similarity in behavior of Ca and Mg made it possible to express $a_{(Ca+Mg)}$. Measurement of this ratio has been considered a useful indication of K supply to plants (Beckett, 1964; Wild, Rowell, and Ogunfowora, 1969; and Graham and Fox, 1971). Measurement of this ratio in relation to the amount of

labile K is known as quantity-intensity (Q/I) technique as proposed by Beckett (1967).

Lime may convert exchangeable K to nonexchangeable forms and induce adsorption of K by soil colloids (Peech and Bradfield, 1943). On four North Carolina soils made homoionic with respect to Ca and Al, Thomas and Coleman (1959) observed that Ca-soil retained more K than did Al-soil due to an increase in effective cation exchange capacity (CEC) with Ca saturation.

Murdock and Rich (1965) studied the effect of lime on K availability in Nason silt loam. Potassium fixation occurred at high pH but did not appear to be associated with greater collapse of the vermiculite present in the soil. It was thought to be due to less competition by H_3O^+ for the specific adsorption sites for K.

Gammon (1957) reported that the first effect of liming on soil K was to reduce exchangeable K. A reduction from 26 to 8 ppm of exchangeable K in Leon fine sand was observed one year after application of 5.9 tons of lime per hectare which changed the pH of the soil from 4.6 to 5.9. Repeated K fertilization following liming increased the exchangeable K in the soil over a three-year period. Bartlett and McIntosh (1969) observed K deficiency in tomato seedlings on a spodosol Ap which was high in extractable Al and pH-dependent CEC, after liming with $CaCO_3$, $CaSiO_3$, $CaHPO_4$, and CaF_2 to pH 6.3. It was hypothesized that positive charges associated with Al were probably neutralized by OH^- , PO_4^{-3} , or F^- thereby increasing the CEC but decreasing percentage saturation of the exchange complex by K.

Coating soluble K fertilizers reduce K losses by leaching and increase K availability to plants (Lawton, 1961). Various materials

have been used experimentally as coatings, the most important being waxes, polymers, and sulfur (Hauck and Koshino, 1971). Examples of polymers used are: acrylic resins, polyurethane, polystyrene, polyethylene, vinyl acetate, polyvinyl chloride-polyvinylidene chloride, and polyacrylate nitrile.

Uncoated slowly soluble K fertilizers such as potassium polyphosphate (KPP) and potassium-calcium pyrophosphate (KCP) have also been studied (Chandler and Musgrave, 1944; Lutrick, 1958; DeMent and Stanford, 1959; Caldwell and Kline, 1963; Hagin, 1966; and Engelstad, 1968). Their studies indicated that those slowly soluble K fertilizers are as effective as the soluble fertilizers and they are less likely to leach.

The efficiency of fertilizers also varies with particle size of the material. Hagin (1966) observed that a powdered form of a KPP was more efficient than the granulated form in calcareous and alkaline soils. DeMent, Terman, and Bradford (1963) observed that K uptake by corn decreased with increasing particle size of KPP mixed through the soil while the reverse was observed for surface applied KCP.

The retention of KCl, K_2SO_4 , and K_3PO_4 were investigated by Ayres and Hagiwara (1953) on some tropical soils of Hawaii. The order of retention of K was as follows: $K_3PO_4 > K_2SO_4 > KCl$. Greater retention of K was observed from the application of a mixture of ammophos and KCl particularly with higher ratio of phosphate to K. Superphosphate or treble superphosphate application with KCl did not significantly reduce K losses possibly because Ca and H were strongly held in contrast with NH_4 from ammophos. The less strongly held NH_4 could allow greater retention of K when ammophos was applied with KCl. The observed increase in retention by adding phosphate was later clarified by the findings of

Mekaru and Uehara (1972). They observed that the CEC of a Hydrandepht increased from 28 to 127 me/100 g by addition of phosphate. They explained that specifically adsorbed anions such as phosphate render the surface of constant potential colloids more negative by changing the zero point of charge to a lower pH.

The efficiency of soluble K fertilizers also varies according to the method of placement in the field. Volk and Bell (1945) observed greater K losses by band placement of fertilizer than by broadcast in Norfolk fine sand. Nolan and Pritchett (1960) also observed greater losses of K from KCl by band placement than broadcast in Arredondo fine sand with sweet potato as an indicator crop. Adams et al. (1967) observed more efficient utilization of K from KCl by Coastal bermudagrass when 154 kg/ha of K was applied in four equal applications than when applied only once.

Leaching of K is influenced by the capacity of the soil to retain cations. This property is determined by the amount and type of clay minerals present and organic matter content of the soil. Mica, montmorillonite, and vermiculite are the clay minerals contributing to the CEC of most soils. The adsorption of K by these minerals may sometimes lead to a condition where K is rendered unavailable or difficultly available to plants. The process is known as fixation although the term "fixed" K is regarded as ambiguous since this fraction of soil K depends on the extraction procedure.

Stanford (1947) showed that micaceous minerals are responsible for K fixation under moist soil conditions while montmorillonite did not fix K except on drying. Drying increased the amount of K fixed by illite but under moist conditions acidified illite fixed little K.

Studies by Mortland, Lawton, and Uehara (1957) indicated that K

fixed by vermiculite and montmorillonite is more easily released by illite and muscovite as shown by electro-dialysis, chemical extraction and plant growth procedures.

While most studies on K fixation were carried out on crystalline minerals, K fixation by amorphous minerals has received considerable attention. The information on K fixation by amorphous aluminosilicates in soils is scarce because of the difficulty in the extraction of amorphous aluminosilicates. Results of a study by van Reeuwijk and de Villiers (1968) on synthetic amorphous aluminosilica gels showed K fixation in varying amounts measured against exchange by different cations.

In Florida, the clay fraction generally constitutes a very small fraction of the whole soil. Hence, organic matter plays a dominant role in the soil's capacity to retain cations (Fiskell, 1970). Florida soils were found to possess a great portion of pH-dependent CEC (Fiskell and Zelazny, 1971 and Zelazny and Fiskell, 1971). Spencer (1954) studied Lakeland, Blanton, Ft. Meade, and Eustis series and found that colloids of these sandy soils adsorb K very weakly and this accounts for the rapid leachability of K in these soils.

The mineralogical composition of the clay fraction of some Florida soils has been studied by Fiskell and McCaleb (1953) and Fiskell et al. (1958). The dominant clay minerals they found in Florida soils were kaolinite and gibbsite. Montmorillonite, vermiculite, quartz, and feldspars were also found but in relatively small amounts.

The contribution of organic matter to soil CEC based on Ba and K adsorption at various pH values was studied by McLean and Owen (1969). Their results indicated that organic exchange sites active for Ba adsorp-

tion from buffered BaCl_2 solution at low pH were not active for K adsorption from unbuffered KCl solution of similar pH. This observation, they explained, was due to nonexchangeable Al associated with organic matter.

Water movement is a very important factor determining extent of K leaching in soils. Water movement takes place through interconnected pores in the soil. Under saturated conditions, the pores are filled with water but the large pores are more effective as conducting channels for water flow. As the soil becomes less saturated, the small pores become more important as conducting channels but the flow path becomes more tortuous (Baver, Gardner, and Gardner; 1972). Thus, the ability of the soil to transmit water or hydraulic conductivity, $K(\theta)$, decreases as water content decreases (Miller and Klute, 1967). Although the saturated hydraulic conductivity is greater in sandy soils than fine textured soils, the change in conductivity with water content is less abrupt in fine textured soils because of wider pore size distribution.

The distribution of pore size and their shapes results in a distribution of velocities of water flow through the interconnected pores. The distribution of flow velocities as well as molecular diffusion are the two primary processes contributing to mixing of fluids during miscible displacement (Day, 1956 and Biggar and Nielsen, 1967).

Adsorption, desorption, and precipitation of solutes may take place as solutes move along with water during flow through the soil. Ion exchange therefore is a very important consideration in modelling for solute movement through the soil. Boast (1973) presented a review of models to describe solute movement in the soil, specifically those based on classical mathematical macroscopic continuum theories. Other models are based upon statistical theories (Day, 1956 and Nakano and Murrmann,

1971) and finite difference theories. Lai and Jurinak (1972) applied the finite difference method to the solution of the material balance equation to describe Na adsorption in one-dimensional flow through the soil. Sodium adsorption on originally Ca-saturated Yolo soil agreed with the values obtained by numerical solution of the theoretical equation.

Rible and Davis (1955) applied the statistical theory together with chromatographic theory of ion exchange in soil columns. The assumptions required for the theory are as follows: 1) occurrence of instantaneous ion-exchange reactions so that the solution flowing through the exchange column is considered in equilibrium with the exchanger, 2) there are negligible effects of ionic diffusion, channeling, turbulent flow, and alteration of the void ratio during solution flow, 3) the exchange capacity of the exchanger is unaltered during solution flow, and 4) the exchange constant remains unchanged over the range of concentration involved. Assumptions 1 and 2 are not recognized to be realistically applicable to soil columns. Their data from Yolo fine sandy loam soil indicated good agreement between theory and experimental results for the replacement of Ca by Mg and by Na. Fair agreement was obtained when Ca replaced Na but not when Ca replaced Mg.

Thomas and Coleman (1959) applied a chromatographic theory to leaching of fertilizer salts in soils. The chromatographic theory employed was one by Walter which considered CEC and ion-exchange equilibrium constant as the only two factors involved. The theory agreed with values of K distribution in the soil initially made homoionic with respect to Ca and Al and eluted with a solution of KCl and then followed with water. With Na as the initial saturating cation, the theory failed

to predict K distribution unless K added was large relative to the amount of Na in the column. Hydrolysis and change in effective CEC of the soil were speculated to be the possible reasons for the lack of agreement with the Na system.

Simultaneous flow of water and solutes under saturated or unsaturated soil water conditions have been studied in the past. In most cases studies have been conducted using soil columns in the laboratory. It has been necessary to apply several assumptions and complex boundary conditions for the calculations of the solutions to the differential equations describing simultaneous flow of solutes and water. For example, most work done in the past assumes a constant flow velocity and a homogeneous porous medium. In the study by Bresler and Hanks (1969) a method was devised for estimating the distribution of a non-interacting solute in the soil in response to varied wetting and drying conditions and allows for a time-dependent flow velocity. Their equation considered only the effect of viscous flow since the effect of diffusion on the flow of solutes was assumed to be very small compared to that of viscous flow.

Warrick, Biggar, and Nielsen (1971) studied simultaneous movement of water and solute for an unsaturated soil under field conditions. The field data indicated that the distribution of chloride (Cl^-) in the soil after it was first applied with irrigation water and then followed with Cl^- -free water can be predicted quantitatively by combining an equation of solute movement and water movement through an unsaturated soil.

Miller, Biggar, and Nielsen (1965) studied Cl^- movement in relation to water movement in Panoche clay loam free of vegetation. Three methods

of water application were compared, 1) continuous ponding, 2) intermittent ponding with 15 cm of water, and 3) intermittent ponding with 5 cm of water. Intermittent leaching and smaller amount of leaching water moved the salt more like a slug, characterized by prominent peaks whereas under continuous ponding, the salt distribution was more uniformly spread through the soil. The experiment showed that Cl^- movement may be altered with the method of water application.

MATERIALS AND METHODS

Field Experiments

Field Experiments on Flue-Cured Tobacco

Field experiments were conducted at the Agricultural Research Center at Live Oak, Florida in 1972 and 1973 to determine the effects of different K fertilizers on yield, composition and quality of flue-cured tobacco (*Nicotiana tabacum* L.). The various K fertilizers studied are summarized in Tables 1 and 2 for the 1972 and 1973 experiments, respectively, together with a description of the treatments associated with each fertilizer. The soil in the area is a Typic Quartzipsamment, siliceous, thermic, and coated, known commonly as Lakeland fine sand.

Both 1972 and 1973 experiments had treatments that were factorial arrangements of fertilizers or method of application and rates of application replicated once in three blocks. However, in the 1972 experiment there were two additional treatments (Table 1). The experimental plots contained four rows 12 m long and 1.2 m apart.

The recommended fertilization for flue-cured tobacco in Suwannee Valley is a split application of about 1800 kg/ha of 4-3.5-10 applied half at planting and half two weeks later plus sidedressing of NH_4NO_3 five weeks after planting at 34 kg N/ha. Tobacco-grade fertilizers contain 1.29% Mg from MgSO_4 and the K is supplied in the form of K_2SO_4 .

In these experiments the tobacco-grade fertilizer was used as a control. It was banded along the rows as recommended, half at planting and half two weeks after planting. The bands were about 8 cm wide and about 10 cm from the plant row. Bands of fertilizer were covered by

Table 1. Treatments in 1972 field experiment on flue-cured tobacco 1/

| Treat- ment No. | Materials | Method of application | Comments |
|-----------------------|--|--|---|
| 1 | NH ₄ NO ₃ -ordinary superphosphate-K ₂ SO ₄ -MgSO ₄ | $\frac{1}{2}$ at planting, $\frac{1}{2}$ two wk after | Tobacco-grade fertilizer |
| 2 | " " " " | All at planting | " " " |
| 3 | " " " " | All K at planting, $\frac{1}{2}$ of base N and P at planting and $\frac{1}{2}$ two wk after planting | K source was sulfur-coated K ₂ SO ₄ with 36% coating (SCK, 36%) ^{2/} |
| 4 | " " " " | All K at planting, $\frac{1}{2}$ of base N and P at planting and $\frac{1}{2}$ two wk after planting | K source was sulfur-coated K ₂ SO ₄ with 18% coating (SCK, 18%) ^{2/} |
| 5 | Osmocote (7-6-17.5)-MgSO ₄ | All at planting | Osmocote (7-6-17.5) is resin-coated 7-6-17.5 |
| 6 | Osmocote N-ordinary superphosphate-K ₂ SO ₄ -MgSO ₄ | " " " | N source was resin-coated NH ₄ NO ₃ , K was K ₂ SO ₄ |
| 7 | NH ₄ NO ₃ -ordinary superphosphate-MgSO ₄ | $\frac{1}{2}$ at planting, $\frac{1}{2}$ two wk after | No K applied |
| 8 | Osmocote (7-6-17.5)-MgSO ₄ | All at planting | Similar to middle rate of treatment 5 except all N including sidedressing, applied at planting |

1/Treatments 1 to 6 applied at rates equivalent to 450, 900, and 1800 kg/ha of tobacco-grade fertilizer (4% N, 3.5% P, 10% K, and 1.29% Mg) and all treatments except 8 received 34 kg N/ha as NH₄NO₃ five weeks after planting, banded beside the row.

2/ Materials provided by Tennessee Valley Authority.

Table 2. Treatments in 1973 field experiment on flue-cured tobacco 1/

| Treat- ment No. | Materials | Method of application | Comments |
|-----------------------|--|--|---|
| 1 | NH_4NO_3 -ordinary superphosphate- K_2SO_4 - MgSO_4 | $\frac{1}{2}$ at planting, $\frac{1}{2}$ two wk after | Tobacco-grade fertilizer |
| 2 | Swift (0-6.5-25)-IBDU- MgSO_4 | All at planting | Swift (0-6.5-25) and IBDU are slowly soluble materials |
| 3 | Swift (0-6.5-25)- NH_4NO_3 - MgSO_4 | " " " | Same as treatment 2 except N source was NH_4NO_3 |
| 4 | NH_4NO_3 -ordinary superphosphate- K_2SO_4 - MgSO_4 | All K at planting, $\frac{1}{2}$ of base N and P at planting and $\frac{1}{2}$ two wk after planting | K source was sulfur-coated K_2SO_4 with 26% coating $\frac{2}{2}$ (SK, 26%) $\frac{2}{2}$ |
| 5 | Osmocote (7-6-17.5)- MgSO_4 | All at planting | Osmocote (7-6-17.5) is resin-coated 7-6-17.5 |
| 6 | NH_4NO_3 -ordinary superphosphate- MgSO_4 | $\frac{1}{2}$ at planting, $\frac{1}{2}$ two wk after | No K applied |

1/ Treatments 1 to 6 applied at rates equivalent to 450, 900, and 1800 kg/ha of tobacco-grade fertilizer (4% N, 3.5% P, 10% K, and 1.29% Mg) and all treatments received 34 kg N/ha as NH_4NO_3 five weeks after planting, banded beside the row.

2/ Material provided by Tennessee Valley Authority.

plowing along the rows. The tobacco-grade fertilizer was applied at three rates: 450, 900, and 1800 kg/ha. Regardless of fertilizer rate, the N was sidedressed at 34 kg N/ha as NH_4NO_3 five weeks after planting. The experimental plots were irrigated with approximately 2.5 cm of water when plants started to wilt.

Other practices recommended in flue-cured tobacco production were also employed in the experiments. These included weed control, pest control, topping, chemical sucker control, harvesting or priming of mature leaves, and curing of harvested leaves (Hawks, 1970). The harvested leaves were cured in gas-fired bulk barns at 35 C to 49 C during the first two weeks and 49 C to 77 C during the next three to four weeks.

Cured leaves from the two inner rows of each plot were weighed. The leaves were graded by federal tobacco inspectors. Yields are reported in kilograms per hectare and their values in dollars per hectare, calculated using the season's average values for each grade of flue-cured tobacco (type 14) reported by U. S. D. A. Consumer and Marketing Service.

Samples for plant tissue analyses were obtained from the bulk samples of cured leaves representing each of the five primings from each plot and oven-dried at 70 C. The oven-dried leaves were crushed by hand, mixed, and midribs were removed. Samples of midrib-free tobacco leaves were ground to pass through a 20-mesh screen in a Wiley mill and stored in air-tight plastic containers.

One-gram samples of the ground leaves were placed in 50-ml beakers and ashed in a muffle furnace at 450 C. After cooling, the ash was moistened with distilled water, dissolved in 20 ml of 40% HCl, and

evaporated to dryness on a hot plate. About 10 ml of distilled water and another 2.25 ml of 40% HCl solution were added and the resultant solution was boiled for a few minutes without drying. The solution was then filtered through #40 Whatman filter paper and diluted to volume in a 50-ml volumetric flask. Potassium was determined using Beckman model B flame spectrophotometer and Ca and Mg using Perkin-Elmer model 303 atomic absorption spectrophotometer. The amounts of K, Ca, and Mg in the tissue are reported as percent of the oven-dry sample.

The analyses of total alkaloids and total reducing sugars were performed in the laboratory of Dr. W. W. Weeks at North Carolina State University.

Soil samples from 0-15, 15-30, 30-45, and 45-60 cm depth were collected weekly from selected plots starting two weeks after planting to determine movement of K. Samples were taken midway between plants in each of the two middle rows using a sampling tube 2.54 cm in diameter. Samples from the two holes were composited, air-dried, and passed through a 2-mm sieve. Five-gram subsamples were shaken with 25 ml of $\text{N NH}_4\text{OAc}$ (pH 4.8) and the extracts filtered through #40 Whatman filter paper prior to analysis for K.

Analyses of variance for yield, value, and soil and plant tissue analyses data from both experiments were performed by Dr. F. G. Martin of the University of Florida Statistics Department using an IBM 360 computer. The 1972 experiment was not a balanced design, therefore additional analyses were required for the two additional treatments. The additional analyses consisted of the comparisons between effects of treatment 7 and those of treatments 1 to 6 and between effects of treatment 8 and that of the second rate of treatment 5 (Table 1).

Duncan's multiple range tests (DMRT) were also performed where effects were statistically significant. Where rate of fertilizer application effects were significant, regression equations, either linear, quadratic, cubic, or quartic, were calculated. Analyses of variance were performed both on overall priming and individual priming data.

Field Experiments on Potassium Leaching

The two field experiments described were almost an acre in size and required tractors and other equipment for operation. Use of those equipment made it difficult to set up tensiometers and suction equipment for a sophisticated leaching study with a growing crop. Therefore, a separate field experiment was set up without tobacco plants to study K movement in relation to movement of water in the soil.

The design of the K leaching experiment was similar to that of Warrick et al. (1971) using tensiometers and soil solution samplers. The tensiometers and soil solution samplers were installed at random location within a 3 m by 3 m area at depths of 15, 30, 45, 60, 75, and 90 cm below the surface. Two sets of soil solution samplers and two sets of tensiometers were used. Each sampler was connected to a suction flask and the flasks were connected in series to a vacuum pump. The method of connecting each of the soil solution samplers to the suction flask is shown diagrammatically in Figure 1. This set up permitted quick and independent suction and withdrawal of a small volume of soil solution from each sampler. Soil water tensions were determined through the mercury manometer of each tensiometer.

A solution sampler consisted of a porous ceramic sup 1.12 cm outside diameter, attached to one end of a plastic tube similar to that used for

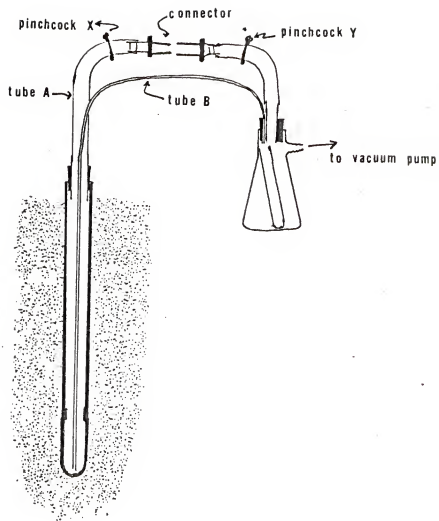


Figure 1. Soil solution sampling apparatus used in the field experiment on K leaching.

the tensiometers. The other end was connected with two Tygon tubes (tubes A and B in Figure 1) through a rubber stopper. The large tube (A) was 0.63 cm in diameter and served as the main suction line. The small tube (B) was 0.16 cm in diameter and delivered solution at the bottom of the sampler to the test tube in the suction flask. The small tube also provided for flushing of the samplers with distilled water prior to each soil solution sampling.

After a few preliminary runs with the set up, a procedure for quick solution sampling was developed wherein small volume increments of soil solution could be extracted and allowed to accumulate. This was important because of the time-dependent movement of water and solutes in the soil. The procedure consisted of applying suction for 3 to 5 min and closing tube A at point X and Y (Figure 1) with pinchcocks, then detaching the tube at the connector. Releasing slowly the pinchcock at point X allows air to enter the solution sampler which would force the solution that was present in the ceramic cup to the test tube in the suction flask. When solution flow stopped as determined visually, tube A was again attached to the vacuum line and pinchcocks at points X and Y were removed. This procedure was repeated several times to all samplers until about 5 ml of soil solution was obtained from each sampler.

A water sprinkler was calibrated to determine output and uniformity of water distribution by using several liter cans placed at various distances from the sprinkler. Three one-hour tests showed that output was 2.5 cm/hr and uniform throughout the experimental area.

The first of two experiments was undertaken on July 3, 1973. Soluble fertilizer (7-6-17.5) was spread evenly over an area of 3 m by 3 m at a rate to supply 180 kg K/ha. About 3 cm of the surface soil was

cultivated with a hand trowel to mix the fertilizer in the soil. After setting the tensiometers and flushing all soil solution samplers, the sprinkler was operated for 2 hr providing a total of 5 cm of water. Tensiometer readings were recorded before application of water and at 1, 7.5, 22, 74, and 122-hr after application of water. Soil solution samples were collected before application of water and after 1, 7.5, 22, 74, and 122 hr. On July 8, 1973 another 2.5 cm of water was applied and solution samples were collected on July 9 and July 13, 1973. There were rainfalls of 1.65 and 2.03 cm during this period, on July 9 (four hours before sampling) and July 12, respectively.

The second experiment was initiated on October 18, 1973. A 3 m by 3 m area was divided into two subplots. In each, one set of tensiometers and one set of soil solution samplers were installed at random location. Resin-coated 7-6-17.5 was applied to one plot and uncoated 7-6-17.5 to the other. Each fertilizer was applied at a rate to supply 180 kg K/ha. The top 3 cm of the soil was mixed with the fertilizer as in the previous experiment and then water was applied continuously for 6 hr at 2.5 cm/hr. Tensiometer readings were recorded before, at the end of water application, and 96 hr after water application. Soil solution samples were collected at 0 and 96 hr after application of water. All soil solution samplers were flushed with distilled water prior to each sampling.

The soil solution samples were analyzed for K. Samples from the second experiment were also analyzed for Ca and Mg in addition to K.

Laboratory Experiments

Leaching Experiments

Laboratory leaching experiments were carried out on reconstituted soil columns to study K leaching under conditions of limited evaporation of water from the soil surface. The water table was controlled and the system did not include plants.

A cylindrical polyvinyl chloride tube, 10 cm inside diameter, 142 cm long, 0.63 cm thick with a lucite sheet glued to the bottom, was used in these experiments. The bottom contained a hole bored in the center into which a tube connector was glued and a piece of Tygon tubing attached. The Tygon tubing was provided for drainage and for regulating the depth of the water table. Ten tensiometer-samplers were installed at 10 cm interval along the side of the cylinder.

Bulk soil samples representing 0-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, and 90+ cm depths were collected. The samples were air-dried, passed through a 2-mm sieve and stored in plastic bags. Based on bulk densities determined from undisturbed soil cores, adequate amounts of each sample were weighed and placed into the cylinder to reconstitute the soil profile. To minimize particle segregation during packing, a large funnel attached to a rubber tube 2 cm in diameter and about 150 cm long was used to deliver soil to the bottom of the plastic cylinder. With the end of the rubber tube touching the bottom of the plastic cylinder, the appropriate soil was poured slowly into the funnel. While slowly raising the tube to allow the soil to flow out, the funnel was continually filled with the appropriate soil.

Two reconstituted columns of Lakeland fine sand were saturated with distilled water from the bottom of the columns and after a week under saturated condition, the columns were allowed to drain to a water table maintained at 125 cm below the surface of the soil. One column was used for the experiment with intermittent application of 2.5 cm of water every five days and the other was used for the experiment with continuous application of 15 cm of water. Applications of water were made with a device constructed from a piece of polyvinyl chloride tube, a piece of lucite, and nine #25 g hypodermic needles. The lucite sheet was glued to the bottom of the polyvinyl chloride tube and the hypodermic needles were glued to the lucite sheet. These needles delivered water on the soil surface as small droplets at a uniform rate maintained by a constant water head in the polyvinyl chloride tube. Five days after application of 2.5 cm of water at 2.5 cm/hr, KCl equivalent to 180 kg K/ha (based on surface area) was mixed in the top 3 cm of the soil and another 2.5 cm of water was applied at the same rate. Soil solution samples were collected after 15 hr. The application of water was repeated three more times at five-day intervals. Soil solution samples were collected each time through each of the ten tensiometer-samplers after 15 hr. All soil solution samplers were flushed with distilled water before soil solution was extracted. The soil solution sampling equipment is shown diagrammatically in Figure 2. In the second soil column, where 15 cm of water were applied continuously soil solution samples were collected only at the end of the water application period. All samples were analyzed for K but samples from the experiment with continuous application of water were also analyzed for Ca and Mg.

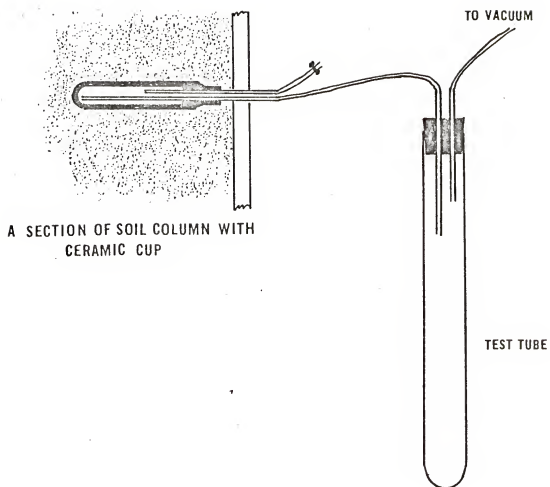


Figure 2. Soil solution sampling apparatus used in the laboratory experiment on K leaching.

Miscible Displacement Studies

To determine K and Cl^- dispersion in Lakeland fine sand during saturated or unsaturated flow of a solution containing KCl, experiments were carried out on reconstituted columns of Lakeland fine sand obtained by packing air-dried samples from 0-10, 10-20, and 20-30 cm depths.

For the saturated case, the soil samples were packed into a glass tube 2.5 cm inside diameter and 30 cm long. One pore volume of 0.01 M KCl solution labelled with 0.01 Ci/ml of Cl^{36} (as NaCl) was applied to the horizontally mounted column and was followed by distilled water. The flow through the soil column was controlled and maintained by a pump. Effluent fractions of 5.5 ml each were collected with a fraction collector starting at the time the KCl solution was introduced into the column. The flow velocities tested were 18, 22, and 69 cm/hr. One pore volume was determined from the actual saturated water content of the soil in the glass tube.

A vertically mounted column was used for the study under unsaturated condition. The apparatus consisted of a soil sample retaining cylinder constructed of perforated stainless steel 10 cm inside diameter and 20 cm long, two stainless steel base plate, and a larger stainless steel cylinder for holding air pressure (Figure 3). Each base plate had two O-rings fitted for the outer and inner cylinders and a porous plate. The base plates also had centered and off-centered nipples that led to the compartment of the ceramic plate. The centered nipple was used for inflow or outflow of liquid and the off-centered nipple was used for flushing the space between the ceramic plate and the base plate. The top base plate had two extra nipples which passed into the space between the outer and inner cylinders, one for air pressure and the other to

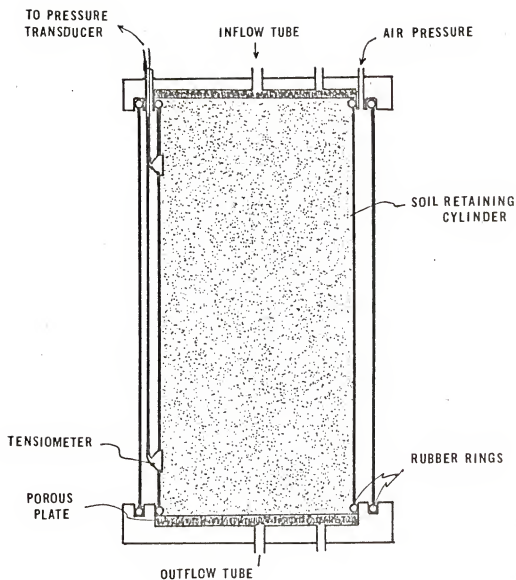


Figure 3. Apparatus used in the miscible displacement study under unsaturated condition.

connect the two tensiometers placed 15 cm apart along one side of the wall of the sample retaining cylinder to a pressure transducer.

After saturating the porous plates under vacuum, the sample retaining cylinder was properly placed on the lower base plate and the soil samples were packed in proper order. After the whole apparatus was assembled the soil was saturated through the bottom plate and allowed 12 hr of equilibration before pressure was introduced for desaturation. During desaturation water was continuously flowing through the soil column at a rate regulated by a pump. The proper rate of flow was determined by trial and error method based on the tensiometer readings of the upper and lower tensiometers. The tensiometers were connected to a pressure transducer and soil water tension was measured potentiometrically after calibration against standard pressure heads. The soil was allowed to attain equilibrium conditions, established as an applied air pressure equivalent 50 cm of water. While water was flowing through the soil at a constant rate, a 0.01 M KCl solution labelled with Cl^{36} was introduced into the soil column. The effluent was collected in 5.5 ml increments with a fraction collector. All fractions were analyzed for K by the usual procedure and for Cl^{36} activity using a Tri-Carb liquid scintillation counter.

Miscellaneous Analyses

The K-Ca exchange characteristic of the soil was determined by quantity-intensity (Q/I) technique proposed by Beckett (1967). Samples were equilibrated with 50 ml of 0.001 M $CaCl_2$ solutions of varying KCl concentrations ranging from 0 to 0.002 M . Equilibration with the solution without K was performed for 0.5, 1.5, 4.5, and 7.0 g samples in 50 ml of

the solution, to determine K release characteristic. For the other solutions (with K) equilibrations were performed using 7.0 g soil samples. The equilibrium solutions were analyzed for Na and K by flame spectroscopy and for Ca and Mg by atomic absorption spectroscopy. The gain or loss of K in the equilibrium solution from that of the original solution was calculated as well as the activity ratio of K to (Ca+Mg) by the use of the Debye-Huckel equation for correcting activities of ions.

Organic matter content of soil samples were determined by the Walkley and Black method (Allison, 1965). Cation exchange capacities were determined from 25 g soil samples by repeated leaching with $\frac{N}{N} \text{NH}_4\text{OAc}$ and then replacement of NH_4 on the soil exchange by leaching with $\frac{N}{N} \text{NaCl}$. The NaCl leachate was analyzed for N by a micro-Kjeldahl distillation procedure, with CEC determined from the amount of NH_4 replaced by Na.

Water retention characteristics of the soil samples were determined in the soil physics laboratory in the Department of Soil Science of the University of Florida, on undisturbed core samples. The core samples were mounted in Tempe cells through which water retention at various applied pressures was determined gravimetrically. A pressure membrane extractor was used for higher applied pressures. Saturated hydraulic conductivity was determined on the same samples and used to calculate hydraulic conductivities at different water contents were calculated following the procedures given by Green and Corey (1971). Calculations were all made with the help of an IBM 360 computer. The plots of water content vs applied pressure were used to determine water contents corresponding to tensiometer readings.

RESULTS AND DISCUSSION

Field Experiments

Field Experiments on Flue-Cured Tobacco

In this manuscript, the term "treatment" refers to fertilizer material or method of application such as for 4-3,5-10 which was applied either split or once in the 1972 experiment. Therefore, the rates of application are not referred to when treatment effects are discussed. Either the fertilizer name or the corresponding treatment number will be used. Complete outlines of the two field experiments may be found in Tables 1 and 2.

Field experiment-1972. The yield; K, total alkaloid, and total reducing sugar contents of the leaves; price per kilogram weight of the cured leaves; and their analysis of variance for the 1972 field experiment on flue-cured tobacco are given in Tables 3 to 16. In the analysis of variance tables, comparison between treatment 8, where all N was applied at planting, and the second rate of treatment 5, where N was applied split, is denoted by "S5, R2 vs S8". The comparison between the check treatment (no K applied) and all other treatments except 8 is denoted by "Ck vs others".

Table 3 contains the yield data by priming and the analysis of variance for these data are in Table 4. Treatments did not result in significant yield differences at any of the five primings but at every priming, except the first, differences in fertilizer rate were significant. In the overall analysis of variance (Table 5), treatment 8 in which all N was applied at planting was significantly lower in yield than treat-

Table 3. Mean yield of flue-cured tobacco in 1972 experiment.

| Treatment No. | Treatment ^{1/} | Rate ^{2/} | Priming | | | | | Total |
|---------------|-------------------------|--------------------|---------|-----|-----|-----|-----|-------|
| | | | 1 | 2 | 3 | 4 | 5 | |
| | | | kg/ha | | | | | |
| 1 | 4-3.5-10 (split) | 1 | 330 | 294 | 302 | 431 | 551 | 1908 |
| | " " | 2 | 379 | 328 | 345 | 445 | 473 | 1970 |
| | " " | 3 | 324 | 333 | 392 | 571 | 717 | 2338 |
| 2 | 4-3.5-10 (once) | 1 | 315 | 284 | 339 | 389 | 540 | 1867 |
| | " " | 2 | 324 | 351 | 283 | 425 | 456 | 1839 |
| | " " | 3 | 300 | 291 | 375 | 349 | 619 | 1934 |
| 3 | SCK (36% coating) | 1 | 342 | 294 | 358 | 388 | 411 | 1793 |
| | " " " | 2 | 336 | 335 | 385 | 466 | 493 | 2015 |
| | " " " | 3 | 325 | 334 | 412 | 500 | 546 | 2117 |
| 4 | SCK (18% coating) | 1 | 329 | 308 | 315 | 424 | 488 | 1864 |
| | " " " | 2 | 337 | 362 | 351 | 465 | 599 | 2114 |
| | " " " | 3 | 370 | 326 | 445 | 451 | 636 | 2228 |
| 5 | Osmocote (7-6-17.5) | 1 | 348 | 361 | 361 | 362 | 511 | 1943 |
| | " " | 2 | 368 | 345 | 366 | 432 | 592 | 2103 |
| | " " | 3 | 331 | 250 | 444 | 611 | 569 | 2305 |
| 6 | Osmocote N | 1 | 348 | 208 | 303 | 399 | 372 | 1630 |
| | " " | 2 | 391 | 400 | 351 | 369 | 295 | 1806 |
| | " " | 3 | 384 | 342 | 417 | 417 | 713 | 2273 |
| 7 | 4-3.5-0 | | 331 | 359 | 348 | 484 | 568 | 2090 |
| 8 | Osmocote (7-6-17.5) | 2 | 352 | 354 | 262 | 334 | 307 | 1609 |

^{1/}See Table 1 for details.^{2/}Rates 1, 2, and 3 correspond to 450, 900, and 1800 kg/ha of 4-3.5-10, respectively.

Table 4. Analysis of variance for yields of flue-cured tobacco from 1972 experiment

| Source of variation | df | Priming | | | | | Total |
|---------------------|----|---------|---------|-------------|---------|----------|----------|
| | | 1 | 2 | 3 | 4 | 5 | |
| Blocks | 2 | 13653** | 14514** | mean square | 20621 | 115662** | 280854** |
| Treatments (S) | 5 | 2829 | 1648 | 23081** | 10793 | 17631 | 68832 |
| Rate | | | | 3581 | | | |
| Linear | 1 | 1 | 5629 | 56299** | 50994** | 199436** | 967144** |
| Quadratic | 1 | 3439 | 22195** | 1123 | 393 | 19716 | 2867 |
| S x Rate | 10 | 842 | 3330 | 1368 | 8391 | 18213 | 28140 |
| S5, R2 vs. S8 | 1 | 294 | 112 | 12788 | 11440 | 97282 | 289960** |
| Ck vs. others | 1 | 348 | 2487 | 227 | 5843 | 5158 | 27029 |
| Error | 38 | 1688 | 2220 | 2825 | 6387 | 12579 | 30045 |

* Significant at the 5% level

** Significant at the 1% level

Table 5. Overall analysis of variance for yields, K uptake, and K, total alkaloid (TA), total reducing sugar (RS) contents of leaves in 1972 field experiment.

| Source of variation | df | Yield | K uptake | %K | %TA | %RS |
|-------------------------|-----|----------|----------|---------|---------|---------|
| ----- mean square ----- | | | | | | |
| Blocks | 2 | 56170** | 143.4** | 5.20** | 3.05** | 1.48 |
| Treatments (S) | 5 | 13766 | 30.7** | 2.12** | 0.37* | 0.12 |
| Rate | | | | | | |
| Linear | 1 | 193428** | 409.3** | 9.83** | 2.69** | 3.63** |
| Quadratic | 1 | 573 | 0.2 | 0.21 | 0.29 | 0.01 |
| S x Rate | 10 | 5628 | 8.7 | 0.37 | 0.37** | 0.11 |
| S5, R2 vs S8 (C1) | 1 | 57992** | 44.5** | 0.31 | 0.29 | 0.31 |
| Ck vs Others (C2) | 1 | 5405 | 96.4** | 10.78** | 4.24** | 0.15 |
| Error (a) | 38 | 6009 | 8.5 | 0.26 | 0.12 | 0.12 |
| Primings (P) | 4 | 317192** | 102.5** | 37.29** | 53.77** | 14.99** |
| P x Treatments | 20 | 5695 | 4.4 | 0.26** | 0.10 | 0.06 |
| P x Rate | 8 | 20653** | 7.7* | 0.23* | 0.11 | 0.36** |
| P x S x Rate | 40 | 6629 | 4.3 | 0.09 | 0.20* | 0.04 |
| P x C1 | 4 | 15981 | 2.7 | 0.22 | 0.01 | 0.11 |
| P x C2 | 4 | 2164* | 7.7 | 0.68** | 0.00 | 0.07 |
| Error (b) | 160 | 6319 | 3.5 | 0.10 | 0.13 | 0.07 |

* Significant at the 5% level

** Significant at the 1% level

ment 5 where 34 kg N/ha was applied five weeks after planting. This suggests that sidedressing of N is beneficial. The yields from the first six treatments did not differ significantly from that of treatment 7 where no K was applied, indicating that K was not limiting tobacco yields in this experiment. Total yields did not vary significantly among treatments (Table 4) but increased linearly with rate of N, P, and K fertilizers. Regression equations for the effect of rate on yields are given in Table 6. Except for the second priming, for which the yield response was quadratic, the responses were linear with rate. These yield responses with rate could not be attributed to K since there was no treatment x rate interaction effect and N and P were also varied with K rate.

The influence of fertilizer treatments and rates on the K contents of the tobacco leaves from each priming are shown in Table 7. The analyses of variance for individual priming data are shown in Table 8. The application of K fertilizer increased the K contents of the leaves from all primings. Increasing rates of fertilizer increased K contents linearly at all primings but the effect was less pronounced in the later primings as indicated by the decreasing value of the regression coefficients given in Table 9. Table 10 shows which treatments significantly influenced K content as determined by Duncan's multiple range tests (DMRT). Treatments 1, 5, and 6 resulted in higher K contents of the leaves than treatments 2, 3, and 4. This indicates that sulfur-coated K_2SO_4 (treatment 3 and 4) possibly had lower solubility thus restricting K availability during periods of high K absorption by the tobacco plants. Treatment 2, where 4-3.5-10 was applied once at planting, had the lowest K in the leaves possibly as a result of K leaching.

The overall analysis of variance for K uptake, the product of yield

Table 6. Regression equations for yield and K uptake based on rate.

| Response | Priming | Equation ^{1/} |
|----------------|---------|-----------------------------|
| Yield | 2 | $180.8 + 135.3R - 24.5 R^2$ |
| Yield | 3 | $295.9 + 29.0 R$ |
| Yield | 4 | $374.2 + 27.6 R$ |
| Yield | 5 | $405.1 + 54.6 R$ |
| Total Yield | | $1722.6 + 120.2 R$ |
| K uptake | 1 | $10.4 + 0.7 R$ |
| K uptake | 2 | $4.2 + 4.7 R - 0.7 R^2$ |
| K uptake | 3 | $7.5 + 1.5 R$ |
| K uptake | 4 | $6.9 + 1.1 R$ |
| K uptake | 5 | $5.2 + 1.3 R$ |
| Total K uptake | | $38.1 + 5.5 R$ |

^{1/} $R = \frac{\text{rate of fertilizer applied (kg/ha)}}{450}$ equivalent to 4-3.5-10.

Table 7. Mean K contents of leaves in 1972 experiment.

| Treatment No. | Treatment ^{1/} | Rate ^{2/} | Priming | | | | |
|---------------|-------------------------|--------------------|---------|-----|-----|-----|-----|
| | | | 1 | 2 | 3 | 4 | 5 |
| 1 | 4-3.5-10 (split) | 1 | 3.5 | 2.8 | 2.8 | 2.0 | 1.4 |
| | " " | 2 | 3.5 | 2.7 | 3.2 | 2.1 | 1.5 |
| | " " | 3 | 4.5 | 3.9 | 4.0 | 2.7 | 1.7 |
| 2 | 4-3.5-10 (once) | 1 | 3.5 | 2.9 | 2.8 | 2.2 | 1.4 |
| | " " | 2 | 3.5 | 2.6 | 2.7 | 2.3 | 1.3 |
| | " " | 3 | 4.0 | 3.3 | 2.9 | 2.4 | 1.6 |
| 3 | SCK (36% coating) | 1 | 2.7 | 2.2 | 2.5 | 1.9 | 1.4 |
| | " " | 2 | 2.8 | 3.1 | 2.8 | 2.0 | 1.4 |
| | " " | 3 | 3.7 | 2.9 | 2.9 | 2.2 | 1.5 |
| 4 | SCK (18% coating) | 1 | 2.8 | 2.5 | 2.7 | 1.8 | 1.4 |
| | " " | 2 | 2.9 | 3.1 | 2.8 | 1.9 | 1.4 |
| | " " | 3 | 3.4 | 2.6 | 3.3 | 2.1 | 1.5 |
| 5 | Osmocote (7-6-17.5) | 1 | 3.6 | 2.9 | 3.0 | 1.9 | 1.4 |
| | " " | 2 | 3.7 | 3.6 | 3.4 | 1.9 | 1.5 |
| | " " | 3 | 4.1 | 3.7 | 3.3 | 2.3 | 1.5 |
| 6 | Osmocote N | 1 | 3.8 | 3.4 | 3.2 | 2.1 | 1.8 |
| | " " | 2 | 3.5 | 3.0 | 3.1 | 2.2 | 1.6 |
| | " " | 3 | 4.1 | 3.6 | 3.5 | 2.3 | 1.9 |
| 7 | 4-3.5-0 | | 1.9 | 2.1 | 2.2 | 1.7 | 1.1 |
| 8 | Osmocote (7-6-17.5) | 2 | 3.2 | 2.9 | 3.2 | 2.2 | 1.6 |

^{1/}See Table 1 for details.^{2/}Rates 1, 2, and 3 are equivalent to 450, 900, and 1800 kg/ha of 4-3.5-10.

Table 8. Analysis of variance for K contents of the leaves in 1972 experiment.

| Source of variations | df | Priming | | | | |
|----------------------|----|-------------|--------|--------|--------|--------|
| | | 1 | 2 | 3 | 4 | 5 |
| | | mean square | | | | |
| Blocks | 2 | 1.19** | 2.32** | 1.28** | 1.07** | 0.34** |
| Treatments (S) | 5 | 0.32** | 0.83* | 0.58** | 0.22** | 0.20** |
| Rate | | | | | | |
| Linear | 1 | 4.51** | 2.79** | 2.33** | 1.14** | 0.37** |
| Quadratic | 1 | 0.69 | 0.02 | 0.00 | 0.00 | 0.04 |
| S x Rate | 10 | 0.09 | 0.42 | 0.16 | 0.04 | 0.02 |
| S5, R2 vs S8 | 1 | 0.35 | 0.68 | 0.08 | 0.13 | 0.01 |
| Ck vs others | 1 | 7.46** | 2.70** | 2.29** | 0.59** | 0.46** |
| Error | 38 | 0.17 | 0.23 | 0.12 | 0.05 | 0.02 |

* Significant at the 5% level.

** Significant at the 1% level.

Table 9. Regression equations for K contents of the leaves based on rate.

| Priming | Equation $\frac{1}{R}$ |
|---------|------------------------|
| 1 | $2.99 + 0.23 R$ |
| 2 | $2.61 + 0.18 R$ |
| 3 | $2.67 + 0.16 R$ |
| 4 | $1.87 + 0.11 R$ |
| 5 | $1.35 + 0.06 R$ |

$$\frac{1}{R} = \frac{\text{rate of fertilizer applied (kg/ha)}}{450} \text{ equivalent to } 4-3.5-10.$$

Table 10. Results from Duncan's multiple range test for treatment means in 1972 experiment.

| Response ^{1/} Priming | | Treatment number ^{2/} | | | | | |
|--------------------------------|---|--------------------------------|----------|----------|----------|----------|----------|
| % K | 1 | <u>1</u> | <u>6</u> | <u>5</u> | <u>2</u> | <u>3</u> | <u>4</u> |
| % K | 2 | <u>5</u> | <u>6</u> | <u>1</u> | <u>2</u> | <u>3</u> | <u>4</u> |
| % K | 3 | <u>1</u> | <u>6</u> | <u>5</u> | <u>4</u> | <u>2</u> | <u>3</u> |
| % K | 4 | <u>2</u> | <u>1</u> | <u>6</u> | <u>5</u> | <u>3</u> | <u>4</u> |
| % K | 5 | <u>6</u> | <u>1</u> | <u>5</u> | <u>2</u> | <u>4</u> | <u>3</u> |
| K uptake | 1 | <u>6</u> | <u>1</u> | <u>5</u> | <u>2</u> | <u>4</u> | <u>3</u> |
| K uptake | 3 | <u>5</u> | <u>6</u> | <u>1</u> | <u>4</u> | <u>3</u> | <u>2</u> |
| Total K uptake | | <u>5</u> | <u>1</u> | <u>6</u> | <u>4</u> | <u>2</u> | <u>3</u> |
| % TA | 2 | <u>3</u> | <u>4</u> | <u>2</u> | <u>1</u> | <u>5</u> | <u>6</u> |

^{1/} Responses with significant effect of treatments.

^{2/} Treatment numbers underscored with same line mean that effects are not significantly different.

and K content, was included in Table 5. Application of K significantly increased K uptake at the first and third priming, and in the total of the five primings. Results from DMRT on treatment means (Table 10) showed higher total K uptake from treatments 1, 5, and 6 than treatments 2, 3, and 4 similar to that observed for K content of the leaves. The response to rate of fertilizer application was linear at every priming except at the second where the response was quadratic (Table 6).

The total alkaloid and total reducing sugar contents of the leaves from each of the five primings are given in Table 11. The analyses of variance are given in Table 12. Neither total alkaloid nor reducing sugar content of flue-cured tobacco varied significantly among treatments except in the second priming. The total alkaloid content increased linearly with rate of fertilizer application from first to fourth priming. Variations between treatment 7 and the other treatments were significant suggesting that higher K levels may be involved in keeping the total alkaloid content of the leaves at a low level. The regression equations based on rate of application for the first, second, and fourth primings are given in Table 13.

Total alkaloid content increased with priming. This is consistent with the general observation with tobacco that nicotine (an alkaloid) increased from the bottom to the top of the tobacco plant (Hawks, 1970). On the other hand, there was no consistent trend for reducing sugar content with regards to priming except that it is highest in either fourth or fifth priming.

The overall analysis of variance (Table 5) indicated a significant priming x treatment x rate interaction for total alkaloid contents. Table 14 shows the mean total alkaloid content from five primings for

Table 11. Mean total alkaloid (TA) and total reducing sugar (RS) contents of flue-cured tobacco leaves in 1972 experiment.

| Treatment No. | Treatment ^{1/} | Rate ^{2/} | Priming | | | | | | | | | |
|------------------|-------------------------|--------------------|---------|------|------|------|------|-----|------|------|------|------|
| | | | 1 | | 2 | | 3 | | 4 | | 5 | |
| | | | TA | RS | TA | RS | TA | RS | TA | RS | TA | RS |
| ----- % ----- | | | | | | | | | | | | |
| 1 | 4-3.5-10 (split) | 1 | 1.43 | 10.7 | 1.45 | 11.4 | 2.27 | 8.5 | 2.63 | 19.9 | 3.38 | 20.4 |
| | " | 2 | 1.29 | 9.2 | 1.57 | 8.3 | 3.00 | 6.5 | 3.44 | 14.4 | 3.63 | 18.1 |
| | " | 3 | 1.58 | 4.7 | 1.62 | 5.4 | 2.81 | 5.0 | 2.81 | 17.2 | 3.32 | 18.6 |
| 2 | 4-3.5-10 (once) | 1 | 1.33 | 7.1 | 1.33 | 12.7 | 1.79 | 7.6 | 2.88 | 17.3 | 3.78 | 18.2 |
| | " | 2 | 1.41 | 11.5 | 1.62 | 13.1 | 2.48 | 7.9 | 2.91 | 16.6 | 3.33 | 19.3 |
| | " | 3 | 1.34 | 5.6 | 1.73 | 7.7 | 3.04 | 5.9 | 3.30 | 14.2 | 3.67 | 17.8 |
| 3 | SCK (36% coating) | 1 | 1.36 | 9.7 | 1.43 | 15.3 | 2.91 | 6.3 | 2.76 | 19.3 | 2.48 | 17.8 |
| | " | 2 | 1.42 | 9.8 | 1.75 | 8.7 | 2.73 | 6.9 | 3.23 | 15.1 | 3.77 | 16.9 |
| | " | 3 | 1.69 | 5.2 | 1.86 | 7.4 | 2.95 | 6.9 | 3.72 | 13.5 | 3.59 | 18.1 |
| 4 | SCK (18% coating) | 1 | 1.24 | 12.3 | 1.30 | 14.3 | 2.83 | 8.9 | 2.57 | 20.1 | 3.59 | 17.1 |
| | " | 2 | 1.58 | 9.8 | 1.57 | 9.5 | 2.61 | 7.2 | 3.26 | 16.4 | 3.56 | 18.7 |
| | " | 3 | 1.61 | 6.4 | 1.89 | 8.4 | 2.52 | 4.5 | 3.45 | 17.2 | 3.15 | 19.6 |
| 5 | Osmocote (7-6-17.5) | 1 | 1.38 | 9.2 | 1.47 | 11.3 | 2.41 | 7.5 | 3.03 | 16.6 | 3.79 | 16.6 |
| | " | 2 | 1.16 | 11.0 | 1.31 | 7.6 | 2.60 | 6.5 | 2.75 | 18.8 | 3.46 | 19.2 |
| | " | 3 | 1.38 | 5.0 | 1.53 | 8.1 | 2.50 | 5.5 | 2.84 | 18.0 | 3.32 | 19.2 |
| 6 | Osmocote N | 1 | 0.95 | 11.8 | 1.03 | 12.8 | 2.23 | 8.7 | 3.12 | 18.2 | 2.93 | 19.9 |
| | " | 2 | 1.16 | 14.1 | 1.13 | 11.6 | 2.29 | 8.0 | 3.21 | 16.5 | 3.99 | 17.0 |
| | " | 3 | 1.68 | 6.9 | 1.48 | 9.4 | 2.85 | 6.7 | 2.94 | 18.0 | 4.15 | 16.7 |
| 7 | 4-3.5-0 | | 1.86 | 10.5 | 1.98 | 7.4 | 3.17 | 6.6 | 3.61 | 15.3 | 4.08 | 16.9 |
| 8 | Osmocote (7-6-17.5) | 2 | 1.09 | 12.5 | 1.05 | 14.3 | 2.38 | 8.8 | 2.65 | 19.4 | 2.99 | 18.4 |

^{1/}See Table 1 for details.

^{2/}Rates 1, 2, and 3 are equivalent to 450, 900, and 1800 kg/ha of 4-3.5-10, respectively.

Table 12. Analysis of variance for total alkaloid and reducing sugar contents of tobacco leaves from 1972 experiment.

| Source of variations | df | Priming | | | | |
|-------------------------|----|---------|--------|--------|--------|--------|
| | | 1 | 2 | 3 | 4 | 5 |
| ----- mean square ----- | | | | | | |
| Total Alkaloids | | | | | | |
| Blocks | 2 | 0.65** | 0.45** | 0.55** | 0.22** | 2.27** |
| Treatments (S) | 5 | 0.07 | 0.23** | 0.24 | 0.14 | 0.09 |
| Rate | | | | | | |
| Linear | 1 | 0.70** | 1.10** | 0.62** | 0.88* | 0.00 |
| Quadratic | 1 | 0.01 | 0.02 | 0.05 | 0.41 | 0.11 |
| S x Rate | 10 | 0.08 | 0.04 | 0.37** | 0.30 | 0.39 |
| S5, R2 vs S8 | 1 | 0.01 | 0.10 | 0.07 | 0.02 | 0.16 |
| Ck vs others | 1 | 0.67** | 0.72** | 0.96** | 0.98* | 0.92 |
| Error | 38 | 0.05 | 0.04 | 0.11 | 0.20 | 0.24 |
| Reducing Sugars | | | | | | |
| Blocks | 2 | 0.27 | 0.72** | 0.47** | 0.43* | 0.17* |
| Treatments (S) | 5 | 0.13 | 0.13 | 0.02 | 0.06 | 0.02 |
| Rate | | | | | | |
| Linear | 1 | 2.36** | 2.26** | 0.43** | 0.33 | 0.00 |
| Quadratic | 1 | 0.66** | 0.23 | 0.00 | 0.26 | 0.00 |
| S x Rate | 10 | 0.06 | 0.06 | 0.02 | 0.08 | 0.05 |
| S5, R2 vs S8 | 1 | 0.03 | 0.67* | 0.07 | 0.01 | 0.01 |
| Ck vs others | 1 | 0.06 | 0.25 | 0.04 | 0.10 | 0.05 |
| Error | 38 | 0.09 | 0.09 | 0.06 | 0.09 | 0.04 |

* Significant at the 5% level.

** Significant at the 1% level.

Table 13. Regression equations for total alkaloid (TA) and reducing sugar (RS) contents of tobacco leaves based on rate.

| Response | Priming | Equation ^{1/} |
|----------|---------|----------------------------|
| % TA | 1 | $1.17 + 0.09 R$ |
| % TA | 2 | $1.23 + 0.11 R$ |
| % TA | 4 | $2.80 + 0.10 R$ |
| % RS | 1 | $0.69 + 0.44 R - 0.12 R^2$ |
| % RS | 2 | $1.40 - 0.16 R$ |
| % RS | 3 | $0.86 - 0.07 R$ |

^{1/} $R = \frac{\text{rate of fertilizer applied (kg/ha)}}{450}$ equivalent to 4-3.5-10.

Table 14. Treatment x rate interaction means for total alkaloid contents of tobacco leaves in 1972 experiment.

| Treatment No. | Rate ^{1/} | | | Equation ^{2/} |
|------------------|----------------------------------|--------------------|--------------------|---------------------------|
| | 1 | 2 | 3 | |
| | ----- % ----- | | | |
| 1 | 2.34 ^{ab} ^{3/} | 2.59 ^a | 2.32 ^{bc} | $1.83 + 0.63R - 0.13R^2$ |
| 2 | 2.22 ^{ab} | 2.35 ^{ab} | 2.63 ^a | $2.08 + 0.14 R$ |
| 3 | 2.39 ^a | 2.58 ^a | 2.76 ^a | $2.29 + 0.12 R$ |
| 4 | 2.24 ^{ab} | 2.53 ^a | 2.58 ^{ab} | $2.21 + 0.10 R$ |
| 5 | 2.43 ^a | 2.23 ^b | 2.29 ^c | No significant regression |
| 6 | 2.05 ^b | 2.36 ^{ab} | 2.62 ^a | $1.92 + 0.18 R$ |

^{1/} Rates 1, 2, and 3 correspond to 450, 900, and 1800 kg/ha of 4-3.5-10, respectively.

^{2/} $R = \frac{\text{rate of fertilizer applied (kg/ha) equivalent to 4-3.5-10.}}{450}$

^{3/} DMRT on treatment means (comparisons within a rate). Values with same letters are not significantly different.

various treatments and rates of application and the regression equations for each treatment based on rate of application.

The total reducing sugar content decreased linearly with rate of application in the second and third priming while response with rate in the first priming was quadratic. The overall analysis of variance (Table 5) indicates that the relationship between rate of application and reducing sugar content is linear.

The grade of flue-cured tobacco is an index of the quality of the cured leaves. Although the market price for a particular grade may vary from year to year, the relative values of the different grades remain about the same. Hence, for statistical purposes the relative prices for the season would be indicative not only of quality for the season but also of the relative values of the grades for any season.

The data on price per kilogram weight of flue-cured tobacco in the 1972 experiment are given in Table 15. Analyses of variance for each of the five primings and that for the total value are given in Table 16. The price of flue-cured tobacco did not vary among treatments. Increasing rate of fertilizer application increased price linearly in the first and third priming. The total value, determined from the products of price and yield from each priming, increased significantly with rate of application.

The data on K, Ca, and Mg content of the soil samples representing four depths and five samplings are given in Tables 17, 18, and 19, respectively. The analyses of variance of the data are given in Table 20. Significant differences due to treatments were observed for K, Ca, and Mg contents of the samples. The effect of treatments on K was independent of sampling time. The DMRT results showed that the soil samples

Table 15. Prices of flue-cured tobacco in 1972 experiment.

| Treatment No. | Treatment ^{1/} | Rate ^{2/} | Priming | | | | |
|---------------|-------------------------|--------------------|---------|------|------|------|------|
| | | | 1 | 2 | 3 | 4 | 5 |
| | | | \$ / kg | | | | |
| 1 | 4-3.5-10 (split) | 1 | 1.84 | 1.88 | 1.91 | 1.88 | 1.89 |
| | " " | 2 | 1.84 | 1.88 | 1.91 | 1.88 | 1.89 |
| | " " | 3 | 1.83 | 1.86 | 1.88 | 1.91 | 1.89 |
| 2 | 4-3.5-10 (once) | 1 | 1.84 | 1.87 | 1.91 | 1.88 | 1.91 |
| | " " | 2 | 1.85 | 1.87 | 1.92 | 1.91 | 1.88 |
| | " " | 3 | 1.84 | 1.87 | 1.88 | 1.88 | 1.91 |
| 3 | SCK (36% coating) | 1 | 1.85 | 1.89 | 1.91 | 1.91 | 1.88 |
| | " " | 2 | 1.86 | 1.89 | 1.91 | 1.91 | 1.87 |
| | " " | 3 | 1.83 | 1.89 | 1.91 | 1.91 | 1.87 |
| 4 | SCK (18% coating) | 1 | 1.85 | 1.89 | 1.89 | 1.81 | 1.89 |
| | " " | 2 | 1.85 | 1.88 | 1.88 | 1.91 | 1.91 |
| | " " | 3 | 1.84 | 1.91 | 1.91 | 1.91 | 1.91 |
| 5 | Osmocote (7-6-17.5) | 1 | 1.85 | 1.88 | 1.91 | 1.89 | 1.88 |
| | " " | 2 | 1.85 | 1.86 | 1.91 | 1.88 | 1.88 |
| | " " | 3 | 1.83 | 1.87 | 1.87 | 1.85 | 1.89 |
| 6 | Osmocote N | 1 | 1.83 | 1.88 | 1.92 | 1.91 | 1.87 |
| | " " | 2 | 1.85 | 1.89 | 1.92 | 1.91 | 1.87 |
| | " " | 3 | 1.83 | 1.87 | 1.91 | 1.85 | 1.88 |
| 7 | 4-3.5-0 | | 1.83 | 1.88 | 1.92 | 1.88 | 1.88 |
| 8 | Osmocote (7-6-17.5) | 2 | 1.84 | 1.89 | 1.91 | 1.88 | 1.89 |

^{1/}See Table 1 for details.^{2/}Rates 1, 2, and 3 are equivalent to 450, 900, 1800 kg/ha 4-3.5-10, respectively.

Table 16. Analysis of variance for price of flue-cured tobacco data in 1972 experiment.

| Source of variations | df | Priming | | | | | Total value |
|----------------------|----|-------------|------|-------|---------|-------|-------------|
| | | 1 | 2 | 3 | 4 | 5 | |
| | | mean square | | | | | |
| Blocks | 2 | 1.67* | 2.15 | 3.01 | 17.12** | 4.72* | 214023** |
| Treatments (S) | 5 | 0.59 | 2.92 | 1.31 | 2.09 | 3.39 | 50856 |
| Rate | | | | | | | |
| Linear | 1 | 3.17** | 0.13 | 5.41* | 2.01 | 2.57 | 694533** |
| Quadratic | 1 | 1.75* | 0.02 | 0.39 | 1.43 | 0.01 | 2905 |
| S x Rate | 10 | 0.22 | 0.54 | 1.42 | 2.41 | 0.82 | 19616 |
| S5, R2 vs S8 | 1 | 0.17 | 2.67 | 0.17 | 0.00 | 0.67 | 207628** |
| Ck vs others | 1 | 0.59 | 0.04 | 1.54 | 0.50 | 0.14 | 18759 |
| Error | 38 | 0.38 | 2.62 | 1.19 | 2.01 | 1.45 | 21527. |

Table 17. Effect of treatments on K contents^{1/}
of soil in 1972 field experiment.

| Treat- ment No. | Treatment ^{2/} | Depth (cm) | | | |
|--------------------|-------------------------|------------|-------|-------|-------|
| | | 0-15 | 15-30 | 30-45 | 45-60 |
| | | ppm | | | |
| 1 | 4-3.5-10 (split) | 63 | 69 | 38 | 26 |
| 2 | 4-3.5-10 (once) | 80 | 144 | 72 | 34 |
| 3 | SCK (36% coating) | 129 | 138 | 51 | 24 |
| 4 | SCK (18% coating) | 115 | 104 | 60 | 25 |
| 5 | Osmocote (7-6-17.5) | 102 | 71 | 56 | 19 |
| 6 | Granular K_2SO_4 | 118 | 164 | 111 | 22 |

^{1/} Means of five samplings and three rates.

^{2/} See Table 1 for details.

Table 18. Treatment x depth interaction means^{1/}
for Ca contents of the soil.

| Treatment No. ^{2/} | Depth ^{3/} | | | | Test results ^{4/} |
|-----------------------------|---------------------|-----|----|----|----------------------------|
| | 1 | 2 | 3 | 4 | |
| | ----- ppm Ca ----- | | | | |
| 1 | 204 | 111 | 92 | 60 | (1) (2 3 4) |
| 2 | 256 | 252 | 58 | 43 | (1 2) (3 4) |
| 3 | 326 | 168 | 77 | 45 | (1) (2 3) (3 4) |
| 4 | 272 | 225 | 69 | 41 | (1 2) (3 4) |
| 5 | 124 | 75 | 40 | 26 | (1 2 3 4) |
| 6 | 169 | 93 | 61 | 34 | (1 2) (2 3 4) |

^{1/}Means of five samplings and three rates.

^{2/}See Table 1 for details.

^{3/}Depths 1, 2, 3, and 4 correspond to depths 0-15, 15-30, 30-45, and 45-60 cm, respectively.

^{4/}Numbers in parentheses represent depths. Parentheses denote non-significant differences among values of Ca content for the depths indicated.

Table 19. Treatment x depth interaction means^{1/}
for Mg contents of the soil.

| Treat- ment No. ^{2/} | Depth ^{3/} | | | | Test results ^{4/} |
|----------------------------------|---------------------|----|----|---|-------------------------------|
| | 1 | 2 | 3 | 4 | |
| | ----- ppm Mg ----- | | | | |
| 1 | 21 | 13 | 7 | 5 | (1 2) (2 3) (3 4) |
| 2 | 19 | 18 | 9 | 6 | (1 2) (3 4) |
| 3 | 29 | 32 | 20 | 6 | (1 2) (3) (4) |
| 4 | 32 | 29 | 21 | 7 | (1 2) (2 3) (4) |
| 5 | 19 | 13 | 9 | 4 | (1 2) (2 3) (3 4) |
| 6 | 30 | 26 | 15 | 4 | (1 2) (3) (4) |

^{1/}Means of five samplings and three rates.

^{2/}See Table 1 for details.

^{3/}Depths 1, 2, 3, and 4 correspond to depths 0-15, 15-30, 30-45, and 45-60 cm, respectively.

^{4/}Numbers in parentheses represent depths. Parentheses denote non-significant differences among values of Mg content for the depths indicated.

Table 20. Analysis of variance for K, Ca, and Mg contents of the soil in 1972 experiment.

| Source of variations | df | K | Ca | Mg |
|----------------------|-----|-------------------------|----------|--------|
| | | ----- mean square ----- | | |
| Blocks | 2 | 82302** | 81907 | 249 |
| Samplings (S) | | | | |
| Linear | 1 | 258 | 2416 | 88 |
| Quadratic | 1 | 1538 | 890 | 17 |
| Cubic | 1 | 19971 | 31641 | 452 |
| Quartic | 1 | 15302 | 208 | 58 |
| Treatments (T) | 5 | 22301* | 84253* | 1583** |
| S x T | 20 | 13370 | 29976 | 97 |
| Error (a) | 58 | 9011 | 28173 | 233 |
| Depth (D) | 3 | 145346** | 639895** | 6889** |
| S x D | 12 | 9206 | 19011 | 229* |
| T x D | 15 | 7141 | 27902 | 185* |
| S x T x D | 60 | 8206 | 14660 | 117 |
| Error (b) | 180 | 6015 | 16222 | 103 |

* Significant at the 5% level.

** Significant at the 1% level.

from plots treated with 4-3.5-10 applied split and resin-coated 7-6-17.5 (treatments 1 and 5) contained significantly less K than plots treated with granular K_2SO_4 and with N supplied from Osmocote (treatment 6). The low soil K contents with treatment 1 could not be explained by K uptake since with treatment 6, the K uptakes were also high. The insignificant effect of treatment x depth interaction made it difficult to explain this result on the basis of relative K location within the soil depth sampled. The data however indicate high K content at 3-45 cm depth with the uncoated granular K_2SO_4 . It may be postulated that K from this fertilizer moved down the soil profile more quickly than K from other fertilizers or treatments. This downward movement did not significantly reduce K contents of the leaves over that of the other treatments. Split application of 4-3.5-10 resulted in relatively lower K contents throughout the soil depth considered while the single application caused higher K contents particularly at 15-30 cm depth. The K contents from both sulfur-coated materials were about twice as great as that from 4-3.5-10 applied split at 0-15 and 15-30 cm depths. Resin-coated 7-6-17.5 seemed to retard K movement to the lower depths more than the other treatments.

Since K retention in the soil is influenced by the ionic composition of the soil solution, the distribution of Ca and Mg in the soil may be useful in explaining the distribution of K in the soil. In this experiment, there seemed to be no relation of Ca or Mg distribution with K distribution in the soil. Treatments caused significant variations in Ca and Mg contents in the soil. Treatments 2, 3, and 4 resulted in greater amounts of Ca in the soil at 0-15 and 15-30 cm depths than treatments 1, 5, and 6. On the other hand, Mg was higher in the first three layers where treatments 3, 4, and 6 were applied. In addition,

a sampling x depth interaction effect was observed to be significant.

Rainfall data for the experimental area from March to August 1972 are given in Table 21. Within the period between the time the fertilizers were applied (April 3) and the fifth soil sampling (May 24), there was a total of 15.05 cm of water added to the soil as rain. This amount fell in fourteen days. The highest amount (5.82 cm) fell on April 23, three days before the first soil sampling, and the second highest (3.50 cm) fell on May 8, two days prior to the second soil sampling. These two rainfalls increased the water content of the soil to a depth of 30 cm as indicated by soil water tension at various depths measured with tensiometers. The plots were irrigated on May 4 with about 2.5 cm of water but this amount did not seem to change the water content at the 30 cm depth. In contrast, the rainfall on April 23 and May 8 increased the water content at the 60 cm depth and even at the 90 cm depth after redistribution. An additional 2.5 cm of water applied on May 24 increased water contents at 15, 30, and 45 cm depths (Table 22).

The data on soil K content, rainfall, and soil water tension during the first five to six weeks after fertilizer application suggest that K from soluble fertilizers may have moved down as far as 60 cm as a result of downward movement of water from rain and irrigation. There were indications that K from slowly soluble K fertilizers did not move as much as it did from soluble fertilizers. The data on K content of the soil may indicate that K from slowly soluble fertilizers could have positional disadvantage in view of the time-dependent position of maximum root activity of tobacco plants. Hall et al. (1953) studied root activity of tobacco by injecting P^{32} solution into the soil at various depths and distances from the plant and measured P^{32} uptake at

Table 21. Rainfall data in 1972 at the experimental site.

| Date | March | April | May | June | July | August |
|-------|----------------|-------|-------|-------|------|--------|
| | ----- cm ----- | | | | | |
| 1 | 0 | T | T | 0 | 0.48 | 3.10 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0.76 |
| 3 | 1.24 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 2.16 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0.23 | 0 | 0 | 2.26 |
| 8 | 0 | 0 | 3.50 | 0 | 0 | T |
| 9 | T | 1.29 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 1.27 | 0 |
| 11 | 0 | 0 | 0 | 0 | T | 0.23 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0.30 | 0 | 1.44 | 0 |
| 15 | 0 | 0 | 0.99 | 0 | 0 | 0 |
| 16 | 0 | 0 | T | 0 | 0.10 | 0 |
| 17 | 0.50 | 0 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 1.03 | 0 | 0 |
| 19 | 0 | 0 | 0.25 | 6.10 | 0 | 0 |
| 20 | 0 | 0 | 0.74 | 5.38 | 0.25 | T |
| 21 | 0 | 0 | 0 | T | 0 | 2.54 |
| 22 | 0.15 | 0 | 0 | 0 | 0 | 0 |
| 23 | 0 | 5.82 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0.23 | 0 | 0 | 0 | 0.30 |
| 25 | 0 | T | 0 | 0.89 | 3.08 | 0.81 |
| 26 | 0 | 0 | 1.85 | 2.16 | 0.56 | 4.88 |
| 27 | 0 | 0 | 0 | 3.53 | T | 5.67 |
| 28 | 0 | 0 | 1.35 | 1.03 | 0 | T |
| 29 | 1.60 | 0 | 1.03 | 0 | 0 | 0 |
| 30 | 6.15 | 1.70 | 0.18 | 0.94 | 0 | 0 |
| 31 | 4.33 | | 0 | | 0 | T |
| Total | 16.13 | 9.04 | 10.42 | 21.06 | 7.18 | 20.55 |

Table 22. Soil water tension^{1/} at various depths, before and after rainfall or irrigation during the five-week soil sampling period in 1972.

| Date | Depth (cm) | | | | |
|-------------------|------------|----|----|----|----|
| | 15 | 30 | 45 | 60 | 90 |
| | | | cm | | |
| April 26 | 85 | 60 | 51 | 30 | 0 |
| " 28 | 95 | 68 | 55 | 36 | 6 |
| May 1 | 83 | 68 | 53 | 36 | 6 |
| " 3 | 159 | 68 | 52 | 42 | 12 |
| " 4 ^{2/} | 183 | 68 | 52 | 44 | 14 |
| " 4 ^{3/} | 111 | 68 | 51 | 40 | 10 |
| " 5 | 81 | 68 | 53 | 44 | 14 |
| " 8 | 149 | 84 | 53 | 50 | 20 |
| " 10 | 71 | 61 | 35 | 30 | 0 |
| " 12 | 137 | 70 | 27 | 40 | 10 |
| " 15 | 509 | 78 | 53 | 46 | 16 |
| " 17 | 163 | 78 | 39 | 46 | 16 |
| " 19 | 143 | 82 | 53 | 50 | 20 |
| " 22 | 143 | 86 | 37 | 52 | 22 |
| " 23 | 671 | 96 | 29 | 54 | 24 |
| " 24 | 71 | 78 | 27 | 56 | 26 |
| " 26 | 57 | 78 | 7 | 54 | 24 |
| " 30 | 75 | 78 | 5 | 52 | 22 |
| " 31 | 99 | 84 | 3 | 52 | 22 |

^{1/} No measurements made prior to April 26.

^{2/} Before irrigation.

^{3/} After irrigation.

various times. They observed a shift in the maximum root activity of tobacco from the top 15 cm to the layer between 15 and 25 cm below the surface, as early as four weeks after planting. Later, the roots at depths between 25 and 45 cm contributed appreciably to the total p^{32} uptake of the plant while the contribution by roots in the top 15 cm declined. It is possible that although K from a soluble fertilizer such as granular K_2SO_4 moves quite readily, the shift in maximum root activity is such that the K may be absorbed before it leaves the root zone. However, if rainfall or irrigation was sufficient to move K to depths lower than the root zone, then there is greater possibility that K leaching will significantly reduce K uptake by plants. In such case, a K source with delayed solubility or slowly soluble property may be an effective source of K.

Field experiment-1973. To further study the effect of K movement on flue-cured tobacco, a second experiment was initiated in 1973. The six fertilizer treatments studied are listed and described in Table 2.

Preplant applications of fertilizers were made on March 23, 1973 but due to bad weather conditions, the seedlings were not planted until March 28, 1973. Approximately 1.14 cm of rain fell between the time of fertilizer application and transplanting. Almost 30 cm of rain fell during the week following transplanting. The water table in the experimental area was at or near the surface for several days. Fortunately, the plants survived although their initial growth was probably slightly hampered. Since there was no apparent runoff within the experimental area, it was decided to continue the experiment. Normally, additional fertilizers would be applied to replace estimated leaching losses but in view of the objective of this experiment, additional fertilizer applications were not made except those originally scheduled such as the sidedressing of NH_4NO_3 five weeks after transplanting.

Data were obtained for each priming as in the 1972 experiment. Data for yield, K content of the leaves, total alkaloid and reducing sugar contents of the leaves, and the results of statistical analyses are given in Tables 23 to 34. Analyses of variance were performed on each priming and on overall priming data. The overall analysis of variance (Table 25) indicated that fertilizer treatments interacted with priming; therefore, the individual priming analysis of variance provides a better way of studying treatment effects.

Yields varied significantly among fertilizer treatments in the third and fifth primings. The total yield varied significantly among treatments and increased linearly with rate of application. The regression equation

Table 23. Mean yield of flue-cured tobacco in 1973 experiment.

| Treatment No. | Treatment ^{1/} | Rate ^{2/} | Priming | | | | | Total |
|---------------|--|--------------------|---------|-----|-----|-----|-----|-------|
| | | | 1 | 2 | 3 | 4 | 5 | |
| | | | kg/ha | | | | | |
| 1 | 4-3.5-10 (split) | 1 | 348 | 295 | 509 | 342 | 508 | 2002 |
| | " " | 2 | 327 | 300 | 453 | 373 | 604 | 2057 |
| | " " | 3 | 342 | 357 | 465 | 405 | 825 | 2394 |
| 2 | Swift (0-6.5-25)-IBDU | 1 | 395 | 349 | 414 | 461 | 258 | 1877 |
| | " " " | 2 | 371 | 323 | 449 | 453 | 455 | 2051 |
| | " " " | 3 | 299 | 333 | 450 | 421 | 529 | 2032 |
| 3 | Swift (0-6.5-25)-NH ₄ NO ₃ | 1 | 290 | 306 | 432 | 464 | 689 | 2181 |
| | " " " | 2 | 328 | 346 | 427 | 503 | 812 | 2416 |
| | " " " | 3 | 280 | 286 | 585 | 500 | 705 | 2356 |
| 4 | SCK (26% coating) | 1 | 319 | 284 | 354 | 436 | 588 | 1981 |
| | " " | 2 | 311 | 309 | 407 | 480 | 773 | 2280 |
| | " " | 3 | 328 | 357 | 356 | 445 | 745 | 2231 |
| 5 | Osmocote (7-6-17.5) | 1 | 303 | 277 | 470 | 451 | 661 | 2162 |
| | " " | 2 | 297 | 358 | 412 | 507 | 647 | 2221 |
| | " " | 3 | 379 | 294 | 386 | 528 | 580 | 2167 |
| 6 | 4-3.5-0 | 1 | 258 | 307 | 447 | 460 | 573 | 2045 |
| | " " | 2 | 262 | 291 | 380 | 444 | 629 | 2006 |
| | " " | 3 | 303 | 316 | 485 | 467 | 655 | 2226 |

^{1/} See Table 2 for details.^{2/} Rates 1, 2, and 3 correspond to 450, 900, and 1800 kg/ha of 4-3.5-10, respectively.

Table 24. Analysis of variance for yields of flue-cured tobacco from 1973 experiment.

| Source of variation | df | Priming | | | | | Total |
|---------------------|----|---------|--------|-------------|---------|-------|---------|
| | | 1 | 2 | 3 | 4 | 5 | |
| Blocks | 2 | 7294* | 6598** | mean square | 57485** | 34990 | 52281 |
| Treatments (S) | 5 | 3777 | 790 | 11196* | 13719 | 90526 | 101264* |
| Rates | | | | | | | |
| Linear | 1 | 2454 | 2556 | 3484 | 2611 | 95052 | 268865* |
| Quadratic | 1 | 492 | 1132 | 4586 | 2610 | 38852 | 55833 |
| S x Rate | 10 | 2265 | 2337 | 6360 | 1634 | 17233 | 26350 |
| Error | 34 | 1904 | 4423 | 3748 | 7741 | 27473 | 21376 |

* Significant at the 5% level.

** Significant at the 1% level.

Table 25. Overall analysis of variance for yields, K uptakes, and K, total alkaloid (TA), and total reducing sugar (RS) contents of leaves in 1973 experiment.

| Source of variation | df | Yield | K uptake | %K | %TA | %RS |
|---------------------|-----|--------------------------|----------|---------|---------|----------|
| | | ----- mean squares ----- | | | | |
| Blocks | 2 | 10456 | 6.24 | 0.09 | 1.19** | 13.77 |
| Treatments (S) | 5 | 20253** | 33.65** | 1.08* | 0.61* | 93.37** |
| Rate | | | | | | |
| Linear | 1 | 53773** | 49.58* | 0.11 | 0.28 | 27.16 |
| Quadratic | 1 | 11167 | 2.62 | 0.14 | 0.46 | 5.70 |
| S x Rate | 10 | 5270 | 13.48 | 0.53 | 0.15 | 21.00 |
| Error (a) | 34 | 4279 | 7.60 | 0.38 | 0.22 | 20.21 |
| Primings (P) | 4 | 697784** | 40.47** | 22.02** | 42.31** | 759.54** |
| P x Treatment | 20 | 24939** | 14.67* | 0.39** | 0.22* | 14.76** |
| P x Rate | 8 | 11111 | 7.48 | 0.09 | 0.23 | 4.32 |
| P x S x Rate | 40 | 6140 | 7.30 | 0.23* | 0.16 | 7.09 |
| Error (b) | 144 | 11460 | 7.95 | 0.14 | 0.12 | 5.84 |

* Significant at the 5% level.

** Significant at the 1% level.

for the response of total yield to rates of fertilizer application was:
 Total yield (kg/ha) = $1995 + 63R$. The total yield response due to rate
 in the 1973 experiment was lower than in 1972.

Results of DMRT (Table 26) showed that the highest total yield was
 obtained with treatment 3 although it was not significantly different
 from that obtained with treatment 4, which contained sulfur-coated K_2SO_4 ,
 nor with treatment 5 which was resin-coated 7-6-17.5. Yields for treat-
 ment 6, where no K was applied, did not vary significantly from yields
 for treatments 1, 2, 4, and 5. In fact, the yields for treatment 6 were
 slightly higher than yields for treatment 2. Similar to the 1972
 experiment, it was not possible to determine whether differences for
 rates were due to N, P, or K since N and P rates varied with K.

The data on K content of the leaves are given in Table 27. The K
 content of the leaves varied significantly among fertilizer treatments
 in the first, second, and fifth primings but the effect in the first
 priming interacted with rate of application (Table 28). To better
 understand the nature of the treatment x rate interaction, the regression
 equations based on rate are given in Table 29 and the results of DMRT on
 treatment means for each rate are given in Table 30. Treatment 5 resulted
 in higher K contents in the first priming even at the lowest rate of
 fertilizer application (Tables 29 and 30). The K content did not vary
 significantly among rates for treatments 3, 4, 5, and 6. In treatments
 1 and 2, the tobacco-grade fertilizer and Swift product 0-6.5-25 with N
 supplied as IBDU, respectively, the K content increased significantly
 with rate of application. Regardless of rate, the highest K content in
 the second priming was obtained from treatment 3, the Swift product
 0-6.5-25 with N supplied as NH_4NO_3 . In the fifth priming, treatment 5,

Table 26. Results of Duncan's multiple range test on treatment means for yield response in 1973 experiment.

| Response ^{1/} | Priming | Treatment number ^{2/} |
|------------------------|---------|---|
| Yield | 3 | <u>3</u> 1 <u>2</u> 6 <u>5</u> 4 |
| Yield | 5 | <u>3</u> 4 1 5 <u>6</u> <u>2</u> |
| Total yield | | <u>3</u> <u>5</u> <u>4</u> <u>1</u> <u>6</u> <u>2</u> |

^{1/} Responses shown are those with significant effect of treatments.

^{2/} Treatment numbers underscored with same line do not vary significantly in their yields.

Table 27. Mean K contents of leaves in 1973 experiment.

| Treatment No. | Treatment ^{1/} | Rate ^{2/} | Priming | | | | |
|---------------|--|--------------------|---------|-----|-----|-----|-----|
| | | | 1 | 2 | 3 | 4 | 5 |
| | | | % | | | | |
| 1 | 4-3.5-10 (split) | 1 | 2.8 | 2.8 | 2.9 | 2.3 | 2.1 |
| | " " | 2 | 3.4 | 3.1 | 2.8 | 2.2 | 1.5 |
| | " " | 3 | 4.1 | 3.9 | 2.9 | 2.2 | 1.9 |
| 2 | Swift (0-6.5-25)-IBDU | 1 | 3.5 | 3.3 | 2.6 | 2.5 | 2.1 |
| | " " " | 2 | 3.4 | 3.1 | 2.4 | 2.2 | 2.2 |
| | " " " | 3 | 2.5 | 3.2 | 3.2 | 2.4 | 2.2 |
| 3 | Swift (0-6.5-25)-NH ₄ NO ₃ | 1 | 3.4 | 4.2 | 2.9 | 2.3 | 2.1 |
| | " " " | 2 | 3.8 | 3.9 | 2.8 | 2.6 | 2.3 |
| | " " " | 3 | 3.1 | 3.8 | 2.7 | 2.1 | 2.2 |
| 4 | SCK (26% coating) | 1 | 3.7 | 3.7 | 3.2 | 2.4 | 1.9 |
| | " " | 2 | 3.2 | 3.6 | 2.9 | 2.5 | 2.1 |
| | " " | 3 | 2.9 | 3.3 | 2.8 | 2.4 | 2.1 |
| 5 | Osmocote (7-6-17.5) | 1 | 4.0 | 3.7 | 2.8 | 2.6 | 2.3 |
| | " " | 2 | 4.3 | 3.9 | 2.8 | 2.7 | 2.1 |
| | " " | 3 | 4.3 | 3.7 | 2.8 | 2.3 | 2.2 |
| 6 | 4-3.5-0 | 1 | 3.3 | 3.2 | 2.7 | 2.2 | 2.0 |
| | " " | 2 | 2.7 | 3.0 | 2.3 | 2.5 | 1.8 |
| | " " | 3 | 3.7 | 3.7 | 3.1 | 2.6 | 2.1 |

^{1/} See Table 2 for details.^{2/} Rates 1, 2, and 3 correspond to 450, 900, and 1800 kg/ha of 4-3.5-10, respectively.

Table 28. Analysis of variance for K contents and total K uptakes in 1973 experiment.

| Source of variation | df | Priming | | | | | Total K uptake |
|---------------------|----|-------------|--------|------|------|--------|----------------|
| | | 1 | 2 | 3 | 4 | 5 | |
| | | mean square | | | | | |
| Blocks | 2 | 0.95 | 0.71 | 0.11 | 0.01 | 0.30** | 31.23 |
| Treatments (S) | 5 | 1.29** | 0.95** | 0.09 | 0.11 | 0.21** | 168.23** |
| Rate | | | | | | | |
| Linear | 1 | 0.00 | 0.22 | 0.10 | 0.04 | 0.02 | 247.89* |
| Quadratic | 1 | 0.01 | 0.07 | 0.43 | 0.05 | 0.07 | 13.12 |
| S x Rate | 10 | 0.77* | 0.32 | 0.21 | 0.09 | 0.08 | 67.41 |
| Error | 34 | 0.30 | 0.26 | 0.17 | 0.07 | 0.05 | 38.02 |

* Significant at 5% level.

** Significant at 1% level.

Table 29. Treatment x rate interaction means and regression equations for K contents.

| Response ^{1/} | Treatment No. | Rate ^{2/} | | | Regression equation ^{3/} |
|------------------------|---------------|--------------------|------|------|-----------------------------------|
| | | 1 | 2 | 3 | |
| | | ----- % ----- | | | |
| % K (1) | 1 | 4.1 | 3.4 | 2.8 | 2.5 + 0.4 R |
| | 2 | 2.5 | 3.4 | 3.5 | 3.9 - 0.3 R |
| | 3 | 3.1 | 3.8 | 3.4 | Not significant |
| | 4 | 2.9 | 3.2 | 3.7 | " " |
| | 5 | 4.3 | 4.3 | 4.0 | " " |
| | 6 | 3.7 | 2.7 | 3.2 | " " |
| K uptake (1) kg/ha | 1 | 14.3 | 11.2 | 9.9 | 8.4 + 1.5 R |
| | 2 | 7.6 | 12.6 | 10.3 | 4.8 + 7.1R - 1.6 R ² |
| | 3 | 8.6 | 12.5 | 9.8 | Not significant |
| | 4 | 9.8 | 9.9 | 11.5 | " " |
| | 5 | 16.2 | 12.7 | 12.0 | 10.3 + 1.4 R |
| | 6 | 11.3 | 7.1 | 8.8 | Not significant |
| K uptake (3) kg/ha | 1 | 13.4 | 13.0 | 14.9 | Not significant |
| | 2 | 14.5 | 10.6 | 10.7 | 8.7 + 1.4 R |
| | 3 | 15.8 | 11.9 | 12.3 | 10.3 + 1.3 R |
| | 4 | 10.0 | 11.9 | 11.2 | Not significant |
| | 5 | 10.7 | 11.8 | 12.9 | " " |
| | 6 | 14.9 | 8.6 | 12.1 | 19.8 + 10.0R + 2.1R ² |

^{1/} Numbers in parenthesis refer to priming.

^{2/} Rates 1, 2, and 3 correspond to 450, 900, and 1800 kg/ha of 4-3.5-10, respectively.

^{3/} R = rate of fertilizer applied (kg/ha) equivalent to 4-3.5-10.
450

Table 30. Results of Duncan's multiple range test on treatment means for responses with treatment x rate interaction effects.

| Response ^{1/} | Rate ^{2/} | Treatment number ^{3/} |
|------------------------|--------------------|---|
| % K (1) | 1 | <u>5</u> <u>4</u> <u>2</u> <u>3</u> <u>6</u> <u>1</u> |
| | 2 | <u>5</u> <u>3</u> <u>1</u> <u>2</u> <u>4</u> <u>6</u> |
| | 3 | <u>5</u> <u>1</u> <u>6</u> <u>3</u> <u>4</u> <u>2</u> |
| K uptake (1) | 1 | <u>5</u> <u>4</u> <u>2</u> <u>1</u> <u>3</u> <u>6</u> |
| | 2 | <u>5</u> <u>2</u> <u>3</u> <u>1</u> <u>4</u> <u>6</u> |
| | 3 | <u>5</u> <u>1</u> <u>6</u> <u>4</u> <u>3</u> <u>2</u> |
| K uptake (3) | 1 | <u>1</u> <u>5</u> <u>3</u> <u>6</u> <u>4</u> <u>2</u> |
| | 2 | <u>1</u> <u>4</u> <u>3</u> <u>5</u> <u>2</u> <u>6</u> |
| | 3 | <u>3</u> <u>6</u> <u>2</u> <u>1</u> <u>5</u> <u>4</u> |
| Price (5) | 1 | <u>3</u> <u>5</u> <u>1</u> <u>4</u> <u>6</u> <u>2</u> |
| | 2 | <u>3</u> <u>4</u> <u>6</u> <u>1</u> <u>2</u> <u>5</u> |
| | 3 | <u>1</u> <u>3</u> <u>4</u> <u>2</u> <u>5</u> <u>6</u> |

^{1/} Numbers in parenthesis refer to priming.

^{2/} Rates 1, 2, and 3 correspond to 450, 900, and 1800 kg/ha of 4-3.5-10, respectively.

^{3/} Same as those given in Table 2.

Osmocote (7-6-17.5), resulted in the highest K content. This suggests that after heavy rains which occurred during the early part of this experiment, more K was still available to the plant whereas K from other fertilizers, particularly the tobacco-grade fertilizer, had leached beyond the effective root zone.

Where no K was applied, the K content of the leaves did not appreciably differ from those of other treatments. Possibly, lateral movement of water in the soil within the experimental area carried considerable amount of K towards the no-K plots. This possibility is supported by the fact that a drainage ditch adjacent to the experimental area may have provided a sufficient hydraulic head to cause lateral water movement during the period of heavy rainfall. The K content of the leaves from the no-K treatment in the 1972 experiment were lower than those in 1973.

The data on K uptake may not evaluate the availability of slowly soluble K fertilizers since K uptake is a function of yields which may have been more dependent on N. The K uptake varied significantly among treatments in the first and fifth priming. The fertilizer treatments interacted with rates in the first and third priming (Table 29). Rates of treatment 1 also increased K uptake linearly. The highest rate of treatment 2 significantly decreased K uptake, thus a quadratic relation was obtained. Potassium uptake for treatment 3 also followed the same trend with rate as treatment 2 except that the regression was not significant. For treatments 2 and 3, the effect on K uptake in the third priming differed from those of the other treatments. Uptake increased linearly with rates of treatments 2 and 3 but for the same rate, higher K uptake was obtained from treatment 3 than treatment 2. Undoubtedly, this was due to the higher yields obtained from treatment 3, possibly

because NH_4NO_3 was a better source of N than IBDU. The application of DMRT (Table 31) confirmed the higher K uptakes from treatment 3 in the fifth priming. Total K uptake also varied significantly among treatments. Treatments 3, 4, and 5 resulted in higher total K uptakes than other treatments. Potassium uptakes from treatments 3 and 5 were significantly higher than those from treatments 1, 2, and 6. This means that except where IBDU was applied as the source of N, the total K uptake was significantly increased when slowly soluble K fertilizers were used. Furthermore, total K uptake increased linearly with rate of fertilizer application according to the equation: Total K uptake (kg/ha) = $53.5 + 1.9R$.

The data on total alkaloid and total reducing sugar content of the leaves are shown in Table 32. Generally, both chemical characteristics of tobacco are lower in the 1973 experiment than in 1972 particularly in the lower leaves which were removed in the first priming. Percent total reducing sugar varied significantly among treatments in the second, third, fourth, and fifth primings while total alkaloid varied only in the second priming (Table 33). The effect of rate was significant only in the first priming for total reducing sugar content and in the fifth priming for total alkaloid content (Table 33) but the general trends with rate were consistent with those in the 1972 experiment, where the total alkaloid content increased with rate of application and total reducing sugar content decreased with rate of application. Treatments 1 and 2 generally caused higher total reducing sugar content in the leaves (Table 34). Total reducing sugar content is reduced by high N content in the plant. Since N from tobacco-grade fertilizer was soluble, leaching of N from this fertilizer probably favored the higher content of total reducing sugar. The slow solubility of N from IBDU in treatment 2 probably reduced the N

Table 31. Results of Duncan's multiple range test on treatment means for K content and K uptake responses in 1973 experiment.

| Response ^{1/} | Priming | Treatment number ^{2/} |
|------------------------|---------|--|
| % K | 2 | <u>3</u> <u>5</u> <u>4</u> <u>6</u> 1 2 |
| % K | 5 | <u>5</u> <u>2</u> <u>3</u> 4 6 1 |
| K uptake | 5 | <u>3</u> <u>4</u> <u>5</u> <u>6</u> <u>1</u> 2 |
| Total K uptake | | <u>3</u> <u>5</u> <u>4</u> 1 6 2 |

^{1/} Responses shown are those with significant effect of treatments.

^{2/} Treatment numbers are same as those given in Table 2.

Table 32. Mean total alkaloid (TA) and total reducing sugar (RS) contents of flue-cured tobacco in 1973 experiment.

| Treatment No. | Treatment ^{1/} | Rate ^{2/} | Priming | | | | | | | | | |
|---------------|---|--------------------|---------|-----|------|------|------|------|------|------|------|------|
| | | | 1 | | 2 | | 3 | | 4 | | 5 | |
| | | | TA | RS | TA | RS | TA | RS | TA | RS | TA | RS |
| ----- % ----- | | | | | | | | | | | | |
| 1 | 4-3.5-10 (split) | 1 | 0.55 | 3.8 | 1.38 | 9.6 | 2.33 | 9.9 | 2.75 | 11.9 | 2.74 | 13.3 |
| | " | 2 | 0.97 | 6.1 | 1.47 | 9.3 | 2.47 | 9.4 | 2.78 | 14.1 | 1.98 | 17.7 |
| | " | 3 | 0.97 | 3.6 | 1.43 | 7.4 | 2.22 | 10.5 | 2.87 | 14.3 | 2.50 | 16.7 |
| ----- | | | | | | | | | | | | |
| 2 | Swift (0-6.5-25)-IBDU | 1 | 0.82 | 5.7 | 1.18 | 10.8 | 1.94 | 14.9 | 2.34 | 13.1 | 3.01 | 13.4 |
| | " | 2 | 0.77 | 4.2 | 1.27 | 9.9 | 1.85 | 15.3 | 3.14 | 11.1 | 2.46 | 13.8 |
| | " | 3 | 0.69 | 4.0 | 1.39 | 8.3 | 2.00 | 11.6 | 2.63 | 11.6 | 3.36 | 10.9 |
| ----- | | | | | | | | | | | | |
| 3 | Swift(0-6.5-25)-NH ₄ NO ₃ | 1 | 0.75 | 2.8 | 1.32 | 3.2 | 2.03 | 8.1 | 2.99 | 8.7 | 2.50 | 12.8 |
| | " | 2 | 0.94 | 3.1 | 1.49 | 3.4 | 2.35 | 6.3 | 2.65 | 9.9 | 2.88 | 11.2 |
| | " | 3 | 0.51 | 2.0 | 1.47 | 3.7 | 2.05 | 11.2 | 3.19 | 10.7 | 3.35 | 8.9 |
| ----- | | | | | | | | | | | | |
| 4 | SCK (26% coating) | 1 | 0.87 | 4.4 | 1.58 | 4.1 | 2.62 | 6.9 | 2.83 | 11.3 | 2.86 | 13.7 |
| | " | 2 | 0.91 | 4.4 | 1.65 | 5.6 | 2.24 | 9.1 | 2.82 | 10.5 | 2.38 | 15.0 |
| | " | 3 | 1.01 | 3.5 | 1.67 | 6.7 | 2.06 | 10.1 | 2.92 | 7.6 | 3.37 | 12.8 |
| ----- | | | | | | | | | | | | |
| 5 | Osmocote (7-6-17.5) | 1 | 0.88 | 3.8 | 1.72 | 4.4 | 2.78 | 6.5 | 3.30 | 8.2 | 3.07 | 12.8 |
| | " | 2 | 0.82 | 3.4 | 1.53 | 3.7 | 2.19 | 10.0 | 3.19 | 9.9 | 2.30 | 15.4 |
| | " | 3 | 1.01 | 4.0 | 1.80 | 6.2 | 2.59 | 7.6 | 3.25 | 10.3 | 2.75 | 15.2 |
| ----- | | | | | | | | | | | | |
| 6 | 4-3.5-0 | 1 | 0.94 | 6.0 | 1.67 | 9.7 | 2.34 | 9.4 | 2.72 | 13.0 | 2.83 | 12.9 |
| | " | 2 | 0.79 | 1.8 | 1.68 | 5.9 | 2.21 | 12.4 | 2.86 | 7.7 | 3.09 | 12.2 |
| | " | 3 | 0.79 | 1.6 | 1.70 | 2.2 | 2.39 | 6.2 | 3.25 | 6.4 | 2.65 | 12.1 |

^{1/}See Table 2 for details.

^{2/}Rates 1, 2, and 3 correspond to 450, 900, and 1800 kg/ha of 4-3.5-10, respectively.

Table 33. Analysis of variance for total alkaloid and total reducing sugar contents of tobacco leaves from 1973 experiment.

| Source of variation | df | Priming | | | | |
|------------------------|----|-------------------------|---------|--------|--------|---------|
| | | 1 | 2 | 3 | 4 | 5 |
| | | ----- mean square ----- | | | | |
| <u>Total Alkaloids</u> | | | | | | |
| Blocks | 2 | 0.51** | 0.16 | 0.51 | 0.04 | 0.76 |
| Treatments (S) | 5 | 0.05 | 0.22* | 0.36 | 0.49 | 0.37 |
| Rate | | | | | | |
| Linear | 1 | 0.00 | 0.11 | 0.11 | 0.16 | 0.53 |
| Quadratic | 1 | 0.03 | 0.01 | 0.07 | 0.01 | 1.59** |
| S x Rate | 10 | 0.07 | 0.02 | 0.12 | 0.22 | 0.37 |
| Error | 34 | 0.07 | 0.08 | 0.17 | 0.21 | 0.20 |
| <u>Reducing Sugar</u> | | | | | | |
| Blocks | 2 | 4.20 | 19.89 | 33.87 | 14.47 | 11.90 |
| Treatments (S) | 5 | 5.43 | 52.06** | 41.61* | 26.56* | 26.73** |
| Rate | | | | | | |
| Linear | 1 | 15.31* | 12.60 | 0.07 | 6.26 | 3.83 |
| Quadratic | 1 | 0.43 | 0.61 | 11.92 | 0.45 | 15.95 |
| S x Rate | 10 | 4.29 | 10.84 | 14.95 | 12.12 | 7.16 |
| Error | 34 | 2.99 | 9.58 | 13.04 | 9.16 | 6.06 |

* Significant at the 5% level.

** Significant at the 1% level.

Table 34. Results of Duncan's multiple range test on treatment means for total alkaloid and reducing sugar contents of the leaves.

| Response ^{1/} | Priming | Treatment number ^{2/} |
|------------------------|---------|---|
| TA | 2 | <u>5</u> <u>1</u> <u>4</u> <u>6</u> <u>3</u> <u>2</u> |
| RS | 2 | <u>2</u> <u>1</u> <u>6</u> <u>4</u> <u>5</u> <u>3</u> |
| RS | 3 | <u>2</u> <u>1</u> <u>6</u> <u>4</u> <u>3</u> <u>5</u> |
| RS | 4 | <u>1</u> <u>2</u> <u>3</u> <u>4</u> <u>5</u> <u>6</u> |
| RS | 5 | <u>1</u> <u>5</u> <u>4</u> <u>2</u> <u>6</u> <u>3</u> |

^{1/} Responses shown are those with significant effect of treatments.

^{2/} Treatment numbers are same as those given in Table 2.

available to the plants to a level that also favored a higher content of reducing sugars in the leaves than treatment 3 where NH_4NO_3 was applied. Total alkaloid content was generally higher where Osmocote (7-6-17.5) was applied and lower where the Swift product (0-6.5-25) was applied.

Table 35 gives the price per kilogram of cured leaves from five primings. The analysis of variance is shown in Table 36. Generally, the prices were higher than those in the 1972 experiment. Where no K was applied (treatment 6), tobacco leaves had lower market value than where K was applied. The market values of the cured tobacco leaves were relatively high in 1973 and the differences among grades of the cured leaves were not reflected on the prices. Although there were significant differences in prices for the first, fourth, and fifth primings, the differences do not indicate any advantage of the slowly soluble K fertilizers over the tobacco-grade fertilizer (Table 37).

Soil samples were collected five times at weekly intervals starting one week after planting at depths of 0-15, 15-30, 30-45, and 45-60 cm from plots treated with 4-3.5-10, Swift (0-6.5-25) with N applied as NH_4NO_3 , SCK (26% coating), Osmocote (7-6-17.5), and 4-3.5-0. The soil was generally wet during the sampling period which may have increased contamination of the samples since the four depth samples were obtained from the same hole using one sampling tube.

The K contents of the soil samples are given in Table 38. In general, the K contents of the soil were lower than those in the 1972 experiment. There were significant differences in K contents of the soil among the five treatments studied (Table 39). The plots treated with Osmocote (7-6-17.5) had higher K content than those with other treatments (Table 40). Surprisingly, the plots with 4-3.5-0 treatment had relatively high soil K

Table 35. Prices corresponding to the grades of flue-cured tobacco in 1973 experiment.

| Treatment No. | Treatment ^{1/} | Rate ^{2/} | Priming | | | | |
|---------------|--|--------------------|-------------------|------|------|------|------|
| | | | 1 | 2 | 3 | 4 | 5 |
| | | | ----- \$/kg ----- | | | | |
| 1 | 4-3.5-10 (split) | 1 | 1.85 | 1.95 | 1.98 | 1.96 | 1.99 |
| | " " | 2 | 1.91 | 1.97 | 1.98 | 1.99 | 1.98 |
| | " " | 3 | 1.87 | 1.95 | 1.98 | 2.00 | 2.00 |
| 2 | Swift (0-6.5-25)-IBDU | 1 | 1.88 | 1.95 | 1.98 | 1.99 | 1.98 |
| | " " " | 2 | 1.89 | 1.95 | 2.00 | 1.99 | 1.98 |
| | " " " | 3 | 1.88 | 1.96 | 1.98 | 1.99 | 1.99 |
| 3 | Swift (0-6.5-25)-NH ₄ NO ₃ | 1 | 1.81 | 1.96 | 2.00 | 1.99 | 1.99 |
| | " " " | 2 | 1.81 | 1.95 | 1.99 | 2.00 | 2.00 |
| | " " " | 3 | 1.77 | 1.95 | 2.00 | 1.98 | 2.00 |
| 4 | SCK (26% coating) | 1 | 1.87 | 1.95 | 1.99 | 1.99 | 1.99 |
| | " " | 2 | 1.87 | 1.96 | 1.99 | 2.00 | 2.00 |
| | " " | 3 | 1.89 | 1.95 | 1.99 | 1.99 | 2.00 |
| 5 | Osmocote (7-6-17.5) | 1 | 1.87 | 1.95 | 1.98 | 1.99 | 1.99 |
| | " " | 2 | 1.85 | 1.96 | 1.96 | 1.97 | 1.96 |
| | " " | 3 | 1.87 | 1.96 | 2.00 | 1.97 | 1.98 |
| 6 | 4-3.5-0 | 1 | 1.93 | 1.95 | 1.99 | 1.98 | 1.99 |
| | " " | 2 | 1.81 | 1.96 | 1.99 | 1.96 | 1.99 |
| | " " | 3 | 1.69 | 1.94 | 1.95 | 1.96 | 1.96 |

^{1/}See Table 2 for details.

^{2/}Rates 1, 2, and 3 correspond to 450, 900, and 1800 kg/ha of 4-3.5-10, respectively.

Table 36. Analysis of variance for price of flue-cured tobacco data in 1973 experiment.

| Source of variation | df | Priming | | | | | Total value |
|---------------------|----|-------------------------|------|-------|-------|--------|-------------|
| | | 1 | 2 | 3 | 4 | 5 | |
| | | ----- mean square ----- | | | | | |
| Blocks | 2 | 38.88* | 0.13 | 4.79* | 0.72 | 1.05 | 5114 |
| Treatments (S) | 5 | 27.86** | 0.15 | 0.86 | 2.71* | 1.37** | 81873** |
| Rate | | | | | | | |
| Linear | 1 | 33.33* | 0.01 | 0.02 | 0.19 | 0.19 | 201980** |
| Quadratic | 1 | 0.08 | 1.59 | 0.01 | 0.25 | 0.25 | 47850 |
| S x Rate | 10 | 13.90 | 0.24 | 1.06 | 1.13 | 1.02** | 22270 |
| Error | 34 | 7.67 | 0.38 | 0.93 | 1.07 | 0.33 | 17062 |

* Significant at the 5% level.

** Significant at the 1% level.

Table 37. Results of Duncan's multiple range test on treatment means for price of flue-cured tobacco and total value in 1973 experiment.

| Response ^{1/} | Priming | Treatment number ^{2/} | | | | | |
|------------------------|---------|--------------------------------|----------|----------|----------|----------|----------|
| Price | 1 | <u>2</u> | <u>1</u> | <u>4</u> | <u>5</u> | <u>6</u> | <u>3</u> |
| Price | 4 | <u>2</u> | <u>4</u> | <u>3</u> | <u>1</u> | <u>5</u> | <u>6</u> |
| Total value | | <u>3</u> | <u>5</u> | <u>4</u> | <u>1</u> | <u>6</u> | <u>2</u> |

^{1/}Responses with significant effect of treatments.

^{2/}Treatment numbers are same as those given in Table 2.

Table 38. Effect of treatments on K contents^{1/}
of soil in 1973 field experiment.

| Treatment No. | Treatments ^{2/} | Depth | Sampling | | | | |
|------------------|--------------------------|-------|----------|-----|----|----|----|
| | | | 1 | 2 | 3 | 4 | 5 |
| | | cm | ppm K | | | | |
| 1 | 4-3.5-10 (split) | 0-15 | 41 | 41 | 33 | 28 | 34 |
| | " " | 15-30 | 45 | 32 | 25 | 29 | 37 |
| | " " | 30-45 | 32 | 21 | 17 | 30 | 36 |
| | " " | 45-60 | 22 | 17 | 11 | 13 | 21 |
| 3 | Swift (0-6.5-25) | 0-15 | 53 | 72 | 33 | 20 | 25 |
| | " " | 15-30 | 52 | 70 | 35 | 35 | 52 |
| | " " | 30-45 | 25 | 20 | 17 | 32 | 81 |
| | " " | 45-60 | 24 | 17 | 13 | 12 | 20 |
| 4 | SCK (26% coating) | 0-15 | 49 | 66 | 64 | 26 | 23 |
| | " " | 15-30 | 41 | 54 | 51 | 74 | 93 |
| | " " | 30-45 | 30 | 36 | 38 | 39 | 42 |
| | " " | 45-60 | 33 | 39 | 21 | 23 | 24 |
| 5 | Osmocote (7-6-17.5) | 0-15 | 63 | 61 | 58 | 45 | 67 |
| | " " | 15-30 | 72 | 122 | 75 | 74 | 74 |
| | " " | 30-45 | 45 | 40 | 32 | 34 | 35 |
| | " " | 45-60 | 36 | 20 | 24 | 22 | 20 |
| 6 | 4-3.5-0 | 0-15 | 57 | 55 | 38 | 22 | 24 |
| | " " | 15-30 | 60 | 42 | 35 | 26 | 31 |
| | " " | 30-45 | 39 | 47 | 16 | 21 | 23 |
| | " " | 45-60 | 24 | 21 | 12 | 15 | 12 |

^{1/} Means of three replications.

^{2/} See Table 2 for details. Treatment numbers are the same as those in Table 2.

Table 39. Analysis of variance on K contents of the soil.

| Source of variation | df | Sampling | | | | |
|---------------------|----|-------------------------|--------|--------|--------|--------|
| | | 1 | 2 | 3 | 4 | 5 |
| | | ----- mean square ----- | | | | |
| Blocks | 2 | 1217* | 2463 | 303 | 321* | 738 |
| Treatments (S) | 4 | 673* | 1947 | 1721* | 2561* | 1482 |
| Error (a) | 8 | 146 | 2929 | 250 | 506 | 662 |
| Depth (D) | 3 | 2623** | 8835** | 3184** | 5133** | 3883** |
| S x D | 12 | 94 | 1024 | 168 | 690* | 1043 |
| Error (b) | 30 | 154 | 1092 | 138 | 310 | 579 |

* Significant at the 5% level.

** Significant at the 1% level.

Table 40. Results of Duncan's multiple range test for sampling x treatment and sampling x depth interaction effects on K content of the soil.

| Sampling ^{1/} | Test results ^{2/} | | | | |
|------------------------|----------------------------|----------|----------|----------|---|
| | <u>Treatments</u> | | | | |
| 1 | <u>5</u> | <u>6</u> | 3 | 4 | 1 |
| 3 | <u>5</u> | <u>4</u> | <u>6</u> | 3 | 1 |
| | <u>Depths</u> | | | | |
| 1 | <u>2</u> | <u>1</u> | <u>3</u> | <u>4</u> | |
| 2 | <u>2</u> | <u>1</u> | <u>3</u> | <u>4</u> | |
| 3 | <u>1</u> | <u>2</u> | <u>3</u> | <u>4</u> | |
| 5 | <u>2</u> | <u>3</u> | <u>1</u> | <u>4</u> | |

^{1/} Samplings with observed significant effect of treatments or depths on K content of the soil.

^{2/} Treatment numbers are the same as those in Table 2. Depths 1, 2, 3, and 4 correspond to depths 0-15, 15-30, 30-45, and 45-60 cm, respectively.

content. Significant differences among depths were found for all five samplings but only the differences in the fourth sampling depended on treatments. Table 41 shows the nature of the treatment x depth interaction in the fourth sampling. The distribution of K in the soil treated with 4-3.5-10 was as homogeneous as the distribution of K in the no-K treated plots. With the other treatments, K contents in the soil were generally highest at about 15-45 cm depth.

One week after transplanting, there were high K contents in the soil where Osmocote (7-6-17.5) was applied. Within the period from fertilizer application to the first soil sampling, about 30.7 cm of rain fell (Table 42), 97% of this amount was received within one week period and about 50% was received in one day (April 4). No soil water tension data were gathered from this experiment since the area was wet most of the time however tensiometers were installed. The high rainfall that occurred probably moved most of the K from the surface layer to lower depths. The slow release property of Osmocote (7-6-17.5) probably prevented immediate loss of K from the surface. The relatively high K content found in the soil of plots treated with 4-3.5-0 presumably was caused by mixing of the soil solution with the nearby plots either internally or by surface runoff or both. It is interesting to note that Osmocote (7-6-17.5) still maintained high K contents in the 0-60 cm layer after those heavy rainfalls. The movement of K to the lower depths with passage of time was indicated by the results of DMRT (Table 40).

Field Experiment on Potassium Leaching

The experiment with intermittent application of water was initiated on July 3, 1973. Immediately after applying the fertilizer, the water

Table 41. Results of Duncan's multiple range test for treatment x depth interaction effects on K content of the soil in fourth sampling.

| Treatment No. ^{1/} | Depth ^{2/} | | | | Test results |
|--------------------------------|---------------------|-------|-------|------|-----------------|
| | 1 | 2 | 3 | 4 | |
| | ----- ppm K ----- | | | | |
| 1 | 28 a ^{3/} | 29 c | 30 ab | 13 a | (3 2 1 4) |
| 3 | 43 a | 111 a | 55 a | 19 a | (2) (3 1) (1 4) |
| 4 | 26 a | 74 b | 39 ab | 23 a | (2) (3 1 4) |
| 5 | 45 a | 74 b | 34 ab | 22 a | (2 1) (1 3 4) |
| 6 | 22 a | 26 c | 21 b | 15 a | (2 1 3 4) |

^{1/} Treatment numbers are the same as those in Table 2.

^{2/} Depths 1, 2, 3, and 4 correspond to depths 0-15, 15-30, 30-45, and 45-60 cm, respectively.

^{3/} DMRT on treatment means. Values of K content within a depth followed by same letter are not significantly different.

Table 42. Rainfall data in 1973 at the experimental site.

| Date | March | April | May | June | July | August |
|-------|----------------|-------|-------|-------|-------|--------|
| | ----- cm ----- | | | | | |
| 1 | 0 | 8.90 | 0 | 0 | 0 | 5.85 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0.25 |
| 3 | 0 | 0.63 | 0 | 0 | 0 | 1.07 |
| 4 | 0 | 16.92 | 0 | 0 | 0 | 0.25 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0.69 |
| 6 | 0 | 0 | 0 | 0.79 | 0 | T |
| 7 | 0 | 0.66 | 0 | 0 | 0 | T |
| 8 | 0.38 | 3.75 | 0 | T | T | 2.03 |
| 9 | 5.18 | 0 | 1.22 | T | 1.65 | 0 |
| 10 | 0.66 | 0 | 0 | 2.80 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | T | 2.03 | 2.13 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0.63 | 2.18 | 0 | 0 |
| 15 | 0 | 0 | 1.44 | 0 | 0 | 3.07 |
| 16 | 0 | 0 | 0 | 0.28 | 0 | 0.48 |
| 17 | 0.35 | 0 | 0 | 0 | 0.84 | 2.89 |
| 18 | 0 | 0 | 0 | 1.17 | 2.26 | 0 |
| 19 | 0 | 0 | 0 | 0 | 2.62 | 1.04 |
| 20 | 0 | 0 | 0 | 1.80 | T | 0 |
| 21 | 0.38 | 0 | 0 | 0.56 | T | |
| 22 | 0 | 0 | 0 | 2.80 | 0 | |
| 23 | 0 | 0 | 0 | T | 0 | |
| 24 | 0 | 0 | 0 | 0 | 0 | |
| 25 | 0.63 | 0 | 1.90 | 0 | 0 | |
| 26 | 0.51 | 3.30 | 0.56 | 0.76 | T | |
| 27 | 0 | 1.83 | 3.30 | 2.10 | 0.05 | |
| 28 | 0 | 0 | 0 | 0 | 1.70 | |
| 29 | 2.74 | 0 | 0 | 0.38 | 1.75 | |
| 30 | 0.25 | 0 | 3.30 | 0 | 1.65 | |
| 31 | 0.14 | | 0.05 | | 1.14 | |
| Total | 11.22 | 35.99 | 12.40 | 15.62 | 15.69 | |

sprinkler system was operated for 2 hr which delivered a total of 5 cm of water over the exoerimental area. The Initial soil water content and K concentration of the soil solution at different depths are given in Table 43. The water contents were determined from tensiometer readings and the soil water retention curve. The water content increased with depth to near saturation. One hour after the first application of 5 cm of water, water content at 15 cm depth increased from 15% to 36% while no change was indicated for depths lower than 15 cm. The K concentration of the soil solution did not change at any depth. After 7.5 hr, the K content increased from 5 to 9 ppm at 15 cm depth and the water content increased at 60 cm depth and above. The increase in water content in the soil at 60 cm was either due to the original water in the soil pushed by the applied water or the applied water reached 60 cm depth. Redistribution of water to lower depth was accompanied by a decrease in water content near the surface and increase in K concentration of the soil solution to 150 ppm after 22 hr. There appeared to be no K movement between 22 and 74 hr after application of water. The soil water tension data indicated that probably water moved upward in response to hydraulic gradient which developed due to evaporation of water from the soil surface. The upward movement of water may have caused dilution or displacement of the soil solution at the 15 cm depth, thus decreasing the concentration of K in the soil solution at 15 cm.

Five days after the first application of 5 cm of water, a second application of 2.5 cm of water was made. A rainfall of 1.65 cm occurred 24 hr after the second application. These two additions resulted in an increase in soil solution K concentration at 15 cm depth from 77 to 450 ppm (Table 44). No other increases were observed at any depth. A rain-

Table 43. Soil water tension (h), water content (θ), and K content at different depths before^{1/} and after the first application of water.

| Depth | h | θ | K | h | θ | K | h | θ | K |
|-----------|--------------------|----------|-----|--------------------|----------|-----|---------------------|----------|-----|
| --- cm -- | | % | ppm | cm | % | ppm | cm | % | ppm |
| | <u>Before</u> | | | <u>After 1 hr</u> | | | <u>After 7.5 hr</u> | | |
| 15 | 87 | 15 | 5 | 29 | 36 | 5 | 56 | 23 | 9 |
| 30 | 64 | 20 | 1 | 64 | 20 | 1 | 61 | 21 | 1 |
| 45 | 49 | 24 | 1 | 49 | 24 | 1 | 46 | 25 | 1 |
| 60 | 35 | 33 | 0 | 35 | 33 | 0 | 34 | 34 | 0 |
| 75 | 19 | 35 | 1 | 19 | 35 | 1 | 19 | 35 | 1 |
| 90 | 6 | 40 | 1 | 6 | 40 | 1 | 6 | 40 | 1 |
| | <u>After 22 hr</u> | | | <u>After 74 hr</u> | | | <u>After 122 hr</u> | | |
| 15 | 74 | 17 | 150 | 90 | 15 | 150 | 99 | 14 | 77 |
| 30 | 64 | 20 | 1 | 68 | 18 | 0 | 70 | 18 | 0 |
| 45 | 47 | 25 | 1 | 52 | 22 | 1 | 55 | 21 | 1 |
| 60 | 34 | 34 | 0 | 37 | 32 | 0 | 40 | 31 | 0 |
| 75 | 17 | 35 | 1 | 22 | 35 | 1 | 25 | 25 | 1 |
| 90 | 5 | 40 | 1 | 6 | 40 | 1 | 11 | 40 | 1 |

^{1/}Water applied was 5 cm at 2.5 cm/hr.

Table 44. Soil water tension (h), water content (θ), and K content at different depths before ^{1/} and after the second application of water.

| Depth | Before | | | After 2 hr | | | After 28 hr | | | After 120 hr | | |
|-------------|--------|----------|-----|------------|----------|------------------|-------------|----------|-----|--------------|----------|-----|
| | h | θ | K | h | θ | K | h | θ | K | h | θ | K |
| -----cm---- | % | | ppm | cm | % | ppm | cm | % | ppm | cm | % | ppm |
| 15 | 99 | 14 | 77 | 69 | 19 | ns ^{2/} | 81 | 16 | 450 | 81 | 16 | 525 |
| 30 | 70 | 18 | 0 | 70 | 18 | " | 66 | 19 | 1 | 65 | 19 | 0 |
| 45 | 55 | 21 | 1 | 55 | 21 | " | 52 | 23 | 1 | 50 | 24 | 1 |
| 60 | 40 | 31 | 0 | 40 | 31 | " | 38 | 31 | 0 | 36 | 32 | 0 |
| 75 | 25 | 35 | 1 | 25 | 35 | " | 24 | 35 | 1 | 23 | 35 | 1 |
| 90 | 11 | 40 | 1 | 11 | 40 | " | 10 | 40 | 1 | 7 | 40 | 1 |

^{1/}Water applied was 2.5 cm at 2.5 cm/hr and rainfall of 1.65 and 2.03 after 24 and 96 hr, respectively.

^{2/}No soil solution sample collected.

fall of 2.03 cm again occurred after 96 hr which increased soil solution K concentration at 15 cm depth from 450 to 525 ppm after 120 hr.

A total of 11.18 cm of water was added to the soil during the experiment. Because of the insensitivity of tensiometer measurements for determining water contents at low soil water tensions, it was difficult to ascertain exactly, based on water content data, how deep the added water moved. Undoubtedly, the 5 cm of water added the first time moved below 15 cm since the water content at this depth increased to 36%. However, the intermittent application of water with a total of 11.18 cm did not appear to have moved fertilizer K down to the 30 cm depth. Thus K was lagging behind the front of water moving downward. The data on miscible displacement which will be discussed later will provide detailed information about the relationship between movement of water and movement of K in the soil. If the water applied in this field experiment had been tagged, for example with tritium, the tracer would precisely indicate the extent of water movement at different times and show how far K was lagging behind.

Table 45 shows the data on soil water tension, water content, and K, Ca, and Mg concentration of the soil solution at different depths before and after continuous application of 15 cm of water at 2.5 cm/hr. In this experiment, the soluble and slowly soluble forms of 7-6-17.5 were compared. The initial water content at various depths particularly near the surface were lower than those in the first experiment. Hence, even if the same amount of water was applied, the effect would probably be different from the first experiment. No soil solution samples were obtained initially because tensiometer readings indicated that the soil was relatively dry and it would have been difficult to collect the

Table 45. Soil water tensions (h), water contents (θ), and movement of K, Ca, and Mg from soluble (S) and slowly soluble (SS) fertilizers (7-6-17.5) following application of 15 cm of water at 2.5 cm/hr.

| Depth | h | θ | K | | Ca | | Mg | |
|---|-----|----------|-----|-----|-----|-----|----|----|
| | | | S | SS | S | SS | S | SS |
| cm | cm | % | ppm | | | | | |
| <u>Before application</u> ^{1/} | | | | | | | | |
| 15 | 126 | 12 | | | | | | |
| 30 | 100 | 14 | | | | | | |
| 45 | 72 | 16 | | | | | | |
| 60 | 68 | 18 | | | | | | |
| 75 | 53 | 29 | | | | | | |
| 90 | 38 | 35 | | | | | | |
| <u>At the end of 6 hr water application</u> | | | | | | | | |
| 15 | 38 | 33 | 250 | 135 | 147 | 28 | 41 | 8 |
| 30 | 36 | 31 | 52 | 75 | 49 | 92 | 15 | 24 |
| 45 | 34 | 32 | 40 | 32 | 32 | 42 | 7 | 12 |
| 60 | 50 | 27 | 12 | 1 | 16 | 25 | 4 | 10 |
| 75 | 45 | 32 | 1 | 1 | 20 | 17 | 8 | 6 |
| 90 | 30 | 38 | 1 | 1 | 17 | 29 | 4 | 7 |
| <u>90 hr after water application</u> | | | | | | | | |
| 15 | 115 | 12 | 180 | 167 | 83 | 41 | 25 | 12 |
| 30 | 100 | 14 | 191 | 122 | 96 | 108 | 34 | 35 |
| 45 | 88 | 13 | 185 | 90 | 321 | 93 | 87 | 30 |
| 60 | 72 | 17 | 105 | 5 | 275 | 37 | 87 | 13 |
| 75 | 57 | 27 | 26 | 3 | 103 | 26 | 39 | 9 |
| 90 | 42 | 34 | 1 | 1 | 19 | 29 | 4 | 7 |

^{1/}No soil solution samples collected before water application.

necessary volume of solution for chemical analysis. However, initial K distribution would not be expected to vary much from the first experiment since this experimental area was adjacent to the first experimental area.

The results showed movement of K from soluble fertilizer to depth of 60 cm and to depth of 45 cm with the slowly soluble fertilizer, after 15 cm of water was applied. Further movement was observed after 90 hr resulting from redistribution of water to lower depths. Potassium from both fertilizers moved to as far as 75 cm depth but much greater amounts of the soluble fertilizer were observed to move than for the slowly soluble fertilizer. The data also indicate movement of Ca and Mg downward in the soil but to a lesser extent where the slowly soluble fertilizer was used.

Values of hydraulic head (sum of soil water tension and depth) for each depth indicated that initially, water was moving upwards. At the end of application of water (6 hr), the values of hydraulic head indicated that water was moving downward and continued to move until about 90 hr when the hydraulic head was almost the same for all depths. If this was so, then there was probably no further downward movement of K after 90 hr except perhaps through diffusion. Evaporation of water from the soil surface may result in an upward movement of water and affect the distribution of K in the soil.

Laboratory Experiments

Some chemical and physical properties of Lakeland fine sand used in these experiments are given in Tables 46 to 47. Organic matter content and CEC of the soil decreased with depth (Table 46). Organic matter content could not account for all the CEC of the soil. The inorganic fractions of this soil; 3% clay and 4% silt according to Hammond, Lundy, and Saxena (1967); contributed the balance of the total CEC. The amount of K, Ca, and Mg extractable with \underline{N} NH_4OAc at both pH levels were highest in the 0-10 cm depth while Al extractable at pH 4.8 was lowest in the 0-10 cm depth (Table 47).

The saturated water content on the average is 38% by volume. The 15-atm water retention decreased with depth from about 3% to 1.5%. The decrease in water content was probably associated with the organic matter content of the soil. Water retention at tensions lower than 15 atm (15000 cm of water) are given in Table 48. Hydraulic conductivity under water-saturated condition varied inconsistently with depth (Table 46). Values of hydraulic conductivity at higher tensions are given in Table 49.

The quantity-intensity (Q/I) relation measured by the amounts of K released or adsorbed by the soil (ΔK) to or from solutions containing K from 0 to 0.002 \underline{M} in 0.001 \underline{M} Ca are given in Table 50. The activity ratio (AR), $a_K/(a_{Ca+Mg})^{1/2}$, of the equilibrium solution is given below each value of ΔK . A plot of ΔK vs AR is the usual way of showing Q/I relation for a soil. However, values of ΔK corresponding to the different values of AR for Lakeland fine sand were very small which made it

Table 46. Some physical and chemical properties of Lakeland fine sand.

| Depth | Organic matter | Cation exchange capacity | Bulk density | Saturated water content | 15-atm water retention | Hydraulic conductivity |
|-------|----------------|--------------------------|--------------|-------------------------|------------------------|------------------------|
| cm | % | me/100g | g/cc | % | % | cm/hr |
| 0-10 | 1.91 | 7.7 | 1.44 | 41.5 | 2.99 | 19.5 |
| 10-20 | 1.63 | 6.3 | 1.48 | 38.0 | 2.68 | 15.8 |
| 20-30 | 1.32 | 5.9 | 1.48 | 34.8 | 2.75 | 10.0 |
| 30-40 | 0.79 | 4.3 | 1.48 | 35.2 | 2.42 | 18.4 |
| 40-50 | 0.64 | 3.5 | 1.45 | 40.0 | 1.99 | 29.0 |
| 50-60 | 0.55 | 2.5 | 1.48 | 40.8 | 1.96 | 28.0 |
| 60-70 | 0.47 | 2.2 | 1.57 | 38.5 | 1.85 | 20.3 |
| 70-80 | 0.30 | 1.9 | 1.56 | 35.5 | 1.72 | 11.2 |
| 80-90 | 0.26 | 1.8 | 1.54 | 40.0 | 1.67 | 27.6 |
| 90+ | 0.13 | 1.3 | 1.50 | 37.2 | 1.54 | 27.6 |

Table 47. Extractable K, Ca, Mg, and Al with 1N NH_4OAc (pH 4.8 and pH 7)

| Depth | K | | Ca | | Mg | | Al | |
|-------|--------|------|--------|-------|--------|------|--------|------|
| | pH 4.8 | pH 7 | pH 4.8 | pH 7 | pH 4.8 | pH 7 | pH 4.8 | pH 7 |
| cm | ppm | | | | | | | |
| 0-10 | 23.9 | 26.0 | 100.6 | 106.5 | 13.7 | 12.7 | 15.0 | 1.0 |
| 10-20 | 8.2 | 7.2 | 49.8 | 51.4 | 4.3 | 3.7 | 25.2 | 1.5 |
| 20-30 | 5.3 | 5.7 | 33.0 | 27.8 | 3.3 | 2.4 | 33.5 | 1.5 |
| 30-40 | 4.6 | 2.9 | 25.2 | 16.1 | 4.4 | 2.2 | 31.2 | 1.0 |
| 40-50 | 4.6 | 5.7 | 21.0 | 16.1 | 2.9 | 2.2 | 34.2 | 1.0 |
| 50-60 | 3.9 | 4.6 | 23.6 | 21.6 | 4.1 | 2.0 | 31.2 | 1.2 |
| 60-70 | 4.3 | 3.9 | 16.1 | 11.9 | 2.7 | 1.8 | 30.5 | 1.2 |
| 70-80 | 3.9 | 3.6 | 20.6 | 12.9 | 3.8 | 2.0 | 30.0 | 1.2 |
| 80-90 | 3.6 | 2.8 | 24.2 | 10.3 | 3.4 | 1.6 | 28.5 | 1.0 |
| 90+ | 3.6 | 3.6 | 29.4 | 30.4 | 4.2 | 2.0 | 25.0 | 1.0 |

Table 48. Moisture retention characteristics of Lakeland fine sand.

| Depth : cm | Desorption pressure (cm) | | | | | | | | | | |
|---------------|--------------------------|----|----|----|----|----|-----|-----|-----|-----|-------|
| | 3.5 | 20 | 30 | 45 | 60 | 80 | 100 | 150 | 200 | 345 | 15000 |
| | % by volume | | | | | | | | | | |
| 0-10 | 41 | 40 | 40 | 35 | 27 | 19 | 16 | 13 | 13 | 11 | 4 |
| 10-20 | 39 | 37 | 36 | 30 | 21 | 16 | 14 | 11 | 10 | 9 | 4 |
| 20-30 | 35 | 35 | 28 | 21 | 16 | 14 | 12 | 11 | 10 | 9 | 5 |
| 30-40 | 37 | 36 | 34 | 25 | 19 | 15 | 13 | 10 | 9 | 7 | 4 |
| 40-50 | 40 | 39 | 35 | 26 | 20 | 15 | 12 | 10 | 9 | 8 | 3 |
| 50-60 | 41 | 40 | 37 | 33 | 28 | 22 | 15 | 10 | 9 | 7 | 3 |
| 60-70 | 39 | 39 | 39 | 35 | 26 | 16 | 13 | 10 | 9 | 7 | 3 |
| 70-80 | 36 | 36 | 36 | 32 | 26 | 16 | 13 | 10 | 9 | 8 | 3 |
| 80-90 | 40 | 39 | 37 | 33 | 21 | 12 | 10 | 7 | 6 | 5 | 3 |
| 90+ | 38 | 37 | 37 | 32 | 21 | 12 | 10 | 7 | 6 | 5 | 2 |

Table 49. Hydraulic conductivity of the soil at different suction.

| Depth cm | Desorption pressure (cm) | | | | | | | | | | |
|-------------|--------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|--|
| | 3.5 | 20 | 30 | 45 | 60 | 80 | 100 | 150 | 200 | 345 | |
| | cm/hr | | | | | | | | | | |
| 0-10 | 2.02E 01 | 1.80E 01 | 1.70E 01 | 9.82E 00 | 2.81E 00 | 3.59E-01 | 9.48E-02 | 1.01E-02 | 2.04E-03 | 1.43E-04 | |
| 10-20 | 1.45E 01 | 1.18E 01 | 9.72E 00 | 4.22E 00 | 8.23E-01 | 1.46E-01 | 4.64E-02 | 4.23E-03 | 5.96E-04 | 3.86E-05 | |
| 20-30 | 9.64E 00 | 9.40E 00 | 8.18E 00 | 3.20E 00 | 7.14E-01 | 1.50E-01 | 5.28E-02 | 6.25E-03 | 1.44E-03 | 3.48E-05 | |
| 30-40 | 1.84E 01 | 1.66E 01 | 1.18E 01 | 3.22E 00 | 7.87E-01 | 1.69E-01 | 5.48E-02 | 7.94E-03 | 2.29E-03 | 3.02E-05 | |
| 40-50 | 2.63E 01 | 2.24E 01 | 1.35E 01 | 3.75E 00 | 9.70E-01 | 1.79E-01 | 5.42E-02 | 6.50E-03 | 1.42E-03 | 4.42E-05 | |
| 50-60 | 2.89E 01 | 2.39E 01 | 1.72E 01 | 1.01E 01 | 4.78E 00 | 1.80E 00 | 3.15E-01 | 1.05E-02 | 1.89E-02 | 7.90E-05 | |
| 60-70 | 1.97E 01 | 1.98E 01 | 2.00E 01 | 1.31E 01 | 4.16E 00 | 4.59E-01 | 1.12E-01 | 1.03E-01 | 1.56E-03 | 5.58E-05 | |
| 70-80 | 1.25E 01 | 1.24E 01 | 1.23E 01 | 7.94E 00 | 3.48E 00 | 3.81E-01 | 8.21E-02 | 6.40E-03 | 9.65E-04 | 5.65E-05 | |
| 80-90 | 2.76E 01 | 2.53E 01 | 2.10E 01 | 1.29E 01 | 2.85E 00 | 2.63E-01 | 7.47E-02 | 3.68E-03 | 5.87E-04 | 2.13E-05 | |
| 90+ | 2.76E 01 | 2.59E 01 | 2.55E 01 | 1.53E 01 | 3.43E 00 | 3.09E-01 | 7.04E-02 | 4.90E-03 | 6.46E-04 | 2.67E-05 | |

Table 50. Quantity-intensity (Q/I) relation of Lakeland fine sand.

| | | | | | | | | | |
|-------|--------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| 0-10 | ΔK ^{1/} | -.102 | -.059 | -.011 | -.007 | +.010 | +.0 | +.055 | +.046 |
| | AR ^{2/} | .067 | .069 | .067 | .066 | .065 | .077 | .083 | .094 |
| 10-20 | ΔK | -.102 | -.059 | -.008 | -.007 | +.011 | +.011 | +.022 | +.040 |
| | AR | .069 | .069 | .068 | .066 | .074 | .083 | .091 | .088 |
| 20-30 | ΔK | -.070 | -.034 | -.018 | -.067 | +.015 | +.015 | +.055 | +.056 |
| | AR | .067 | .067 | .066 | .066 | .072 | .075 | .081 | .092 |
| 30-40 | ΔK | -.102 | -.034 | -.017 | -.013 | +.011 | +.027 | +.046 | +.040 |
| | AR | .068 | .068 | .066 | .063 | .073 | .077 | .082 | .091 |
| 40-50 | ΔK | -.102 | -.034 | -.017 | -.005 | +.019 | +.014 | +.046 | +.040 |
| | AR | .069 | .066 | .064 | .066 | .071 | .074 | .079 | .092 |
| 50-60 | ΔK | -.102 | -.025 | -.017 | -.005 | +.014 | +.014 | +.027 | +.040 |
| | AR | .069 | .067 | .066 | .067 | .076 | .074 | .082 | .070 |
| 60-70 | ΔK | -.102 | -.034 | -.011 | -.007 | +.011 | +.029 | +.040 | +.064 |
| | AR | .068 | .068 | .068 | .069 | .072 | .079 | .090 | .092 |
| 70-80 | ΔK | -.102 | -.034 | -.011 | -.007 | +.014 | +.027 | +.055 | +.000 |
| | AR | .067 | .068 | .064 | .065 | .073 | .075 | .082 | .093 |
| 80-90 | ΔK | -.102 | -.025 | -.008 | -.005 | +.002 | +.100 | +.027 | +.040 |
| | AR | .064 | .066 | .068 | .067 | .073 | .076 | .083 | .092 |
| 90+ | ΔK | -.102 | -.025 | -.008 | -.007 | +.018 | +.014 | +.027 | +.055 |
| | AR | .062 | .065 | .066 | .068 | .076 | .077 | .081 | .091 |

^{1/}Amount of K (me/100 g) released (-) or adsorbed (+)
by the soil to or from the solution.

^{2/}Activity ratio of equilibrium solution in $(M/l)^{\frac{1}{2}}$.

difficult to present the Q/I relation in graphical form. The data however indicated that the amount of K released or adsorbed by the soil ranged from -0.1 to about +0.05 me/100 g, or about -40 to +20 ppm K in the soil, respectively. This suggests that the amount of K obtained from the soil by equilibrating the soil with \underline{N} NH_4OAc at both pH levels (Table 47) underestimates the amount of K on the exchange complex. The presence of other cations on the exchange complex with greater affinity than K probably reduced adsorption of K by this soil.

The water content at different depths in the column initially and at various times after application of water are given in Tables 51, 52, 53, and 54 for the first, second, third, and fourth water applications, respectively. The K concentration of the soil solution at different depths in the column collected 15 hr after each application of water is shown in Figure 4.

At the start of the experiment, the soil at 90 cm depth was saturated (Table 51), presumably due to the capillary fringe of the water table which was located at 120 cm below the soil surface. There was an increase in water content in the upper portion of the column immediately following the first addition of water which decreased gradually with time following redistribution of water to the lower part of the column. The downward movement of water affected an increase in water content as far as 60 cm depth after 9 hr but this does not necessarily mean that the applied water had reached 60 cm. The applied water may be pushing down the solution initially present in the soil and if a soil layer below has relatively low conductivity, it would result in an accumulation of water above that layer. The second, third, and fourth applications of water resulted in similar water contents in the column prior to each application.

Table 51. Soil water tension (h) and water content (θ) before ($t=0$) and after the first application of 2.5 cm of water at the rate of 2.5 cm/hr^{1/}

| Depth | : t=0 | | : t=1 | | : t=1.25 | | : t=3 | | : t=4 | |
|--------|------------|----------|-------------|----------|-------------|----------|-------------|----------|--------------|----------|
| | h | θ | h | θ | h | θ | h | θ | h | θ |
| cm | cm | % | cm | % | cm | % | cm | % | cm | % |
| 0-10 | 118 | 15 | 15 | 41 | 23 | 40 | 47 | 34 | 55 | 29 |
| 10-20 | 109 | 13 | 97 | 14 | 48 | 28 | 43 | 31 | 44 | 30 |
| 20-30 | 92 | 15 | 92 | 15 | 92 | 15 | 84 | 15 | 62 | 21 |
| 30-40 | 88 | 13 | 88 | 13 | 88 | 13 | 87 | 14 | 70 | 16 |
| 40-50 | 78 | 15 | 78 | 15 | 78 | 15 | 78 | 15 | 75 | 15 |
| 50-60 | 68 | 19 | 68 | 19 | 68 | 19 | 68 | 19 | 68 | 19 |
| 60-70 | 58 | 27 | 58 | 27 | 58 | 27 | 58 | 27 | 58 | 27 |
| 70-80 | 47 | 31 | 47 | 31 | 47 | 31 | 47 | 31 | 47 | 31 |
| 80-90 | 37 | 35 | 37 | 35 | 37 | 35 | 37 | 35 | 37 | 35 |
| 90-100 | 27 | 37 | 27 | 37 | 27 | 37 | 27 | 37 | 27 | 37 |
| | <u>t=9</u> | | <u>t=15</u> | | <u>t=27</u> | | <u>t=45</u> | | <u>t=108</u> | |
| 0-10 | 71 | 21 | 82 | 18 | 96 | 16 | 106 | 15 | 116 | 15 |
| 10-20 | 67 | 19 | 77 | 17 | 88 | 15 | 104 | 14 | 118 | 13 |
| 20-30 | 69 | 18 | 77 | 16 | 89 | 15 | 97 | 14 | 100 | 14 |
| 30-40 | 70 | 16 | 73 | 16 | 85 | 14 | 88 | 13 | 90 | 13 |
| 40-50 | 74 | 15 | 74 | 15 | 78 | 15 | 78 | 15 | 80 | 14 |
| 50-60 | 66 | 19 | 66 | 19 | 68 | 19 | 69 | 18 | 70 | 18 |
| 60-70 | 56 | 28 | 56 | 28 | 58 | 27 | 59 | 27 | 60 | 26 |
| 70-80 | 46 | 32 | 46 | 32 | 47 | 31 | 49 | 31 | 50 | 30 |
| 80-90 | 37 | 36 | 37 | 36 | 37 | 36 | 38 | 35 | 40 | 35 |
| 90-100 | 27 | 37 | 27 | 37 | 27 | 37 | 28 | 37 | 29 | 37 |

^{1/} "t" refers to time in hours after application of water.

Table 52. Soil water tension (h) and water content (θ) before and at different times (in hours) after the second application of 2.5 cm of water at the rate of 2.5 cm/hr.

| Depth | Before | | t=15 | | t=24 | | t=33.5 | | t=58 | | t=72 | |
|--------|--------|----------|------|----------|------|----------|--------|----------|------|----------|------|----------|
| | h | θ | h | θ | h | θ | h | θ | h | θ | h | θ |
| cm | cm | % | cm | % | cm | % | cm | % | cm | % | cm | % |
| 0-10 | 117 | 15 | 81 | 18 | 91 | 17 | 99 | 16 | 112 | 15 | 118 | 15 |
| 10-20 | 118 | 13 | 76 | 17 | 84 | 16 | 93 | 15 | 105 | 14 | 109 | 13 |
| 20-30 | 100 | 14 | 77 | 16 | 82 | 16 | 88 | 15 | 99 | 14 | 101 | 14 |
| 30-40 | 90 | 13 | 77 | 15 | 79 | 15 | 84 | 14 | 90 | 13 | 91 | 13 |
| 40-50 | 80 | 14 | 78 | 15 | 74 | 15 | 77 | 15 | 80 | 14 | 82 | 14 |
| 50-60 | 70 | 18 | 70 | 18 | 66 | 20 | 68 | 19 | 71 | 18 | 72 | 17 |
| 60-70 | 60 | 26 | 59 | 27 | 56 | 28 | 57 | 27 | 61 | 25 | 62 | 24 |
| 70-80 | 50 | 30 | 49 | 30 | 46 | 32 | 48 | 31 | 51 | 30 | 52 | 29 |
| 80-90 | 40 | 35 | 39 | 35 | 36 | 36 | 38 | 35 | 41 | 34 | 42 | 34 |
| 90-100 | 29 | 37 | 30 | 36 | 26 | 37 | 28 | 37 | 31 | 36 | 31 | 36 |

Table 53. Soil water tension (h) and water content (θ) before and at different times (in hours) after the third application of 2.5 cm of water at the rate of 2.5 cm/hr.

| Depth | Before | | t=15 | | t=120 | |
|--------|--------|----------|------|----------|-------|----------|
| | h | θ | h | θ | h | θ |
| cm | cm | % | cm | % | cm | % |
| 0-10 | 118 | 15 | 88 | 17 | - | - |
| 10-20 | 109 | 13 | 82 | 16 | 111 | 13 |
| 20-30 | 100 | 14 | 82 | 16 | 96 | 15 |
| 30-40 | 91 | 13 | 79 | 15 | 93 | 13 |
| 40-50 | 82 | 14 | 75 | 15 | 84 | 14 |
| 50-60 | 72 | 17 | 66 | 19 | 75 | 17 |
| 60-70 | 62 | 24 | 59 | 27 | 65 | 22 |
| 70-80 | 52 | 30 | 49 | 31 | 55 | 28 |
| 80-90 | 42 | 34 | 38 | 35 | 45 | 33 |
| 90-100 | 31 | 36 | 28 | 37 | 35 | 36 |

Table 54. Soil water tension (h) and water content (θ) before and 15 hr after the fourth application of 2.5 cm of water at the rate of 2.5 cm/hr.

| Depth | Before | | After 15 hr | |
|--------|--------|----------|-------------|----------|
| | h | θ | h | θ |
| cm | cm | % | cm | % |
| 0-10 | 120 | 14 | 78 | 19 |
| 10-20 | 111 | 13 | 72 | 18 |
| 20-30 | 95 | 14 | 74 | 17 |
| 30-40 | 93 | 13 | 83 | 14 |
| 40-50 | 84 | 14 | 80 | 15 |
| 50-60 | 74 | 17 | 71 | 18 |
| 60-70 | 65 | 22 | 61 | 25 |
| 70-80 | 55 | 28 | 51 | 30 |
| 80-90 | 45 | 33 | 41 | 34 |
| 90-100 | 35 | 36 | 31 | 36 |

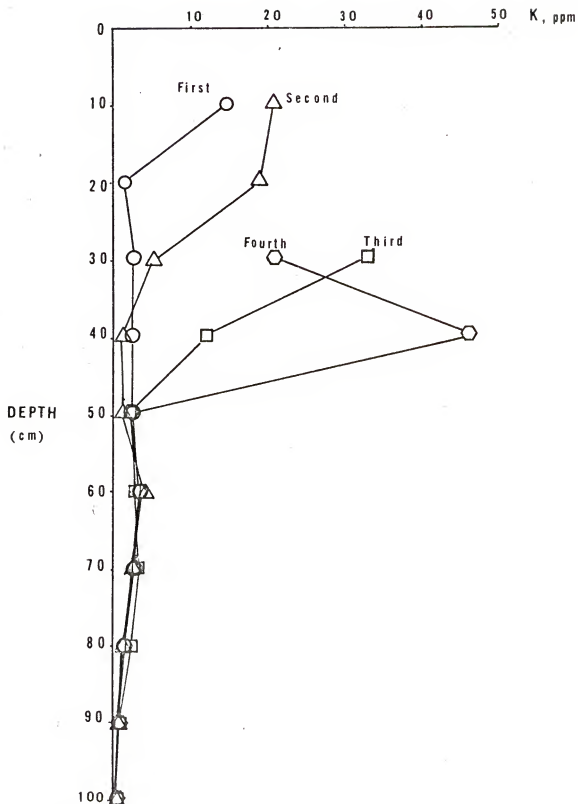


Figure 4. Potassium concentration in soil solution at different depths 15 hr after the first, second, third, and fourth application of 2.5 cm of water at 2.5 cm/hr rate.

Data on K concentration of the soil solution at 10 and 20 cm depth for the third and fourth applications of water were not obtained because of the difficulty in collecting enough volume of solution for analysis. It is very apparent however, that K moved downward in the soil column as a result of movement of the applied water. The front of the water applied through the fourth application theoretically should reach the 60 cm depth assuming the following: 1) the applied water displaced the water initially present in the column, 2) the initial water content was attained after redistribution of the applied water, 3) there was no buildup in water content at sampling time, and 4) no removal of water occurred (by evaporation for example) except through the bottom of the column when maintaining the hydrostatic pressure at 120 cm below the soil surface where the water table was initially located. Collecting soil solution samples would decrease the value of the theoretical depth. Since the amount of each sample collected in the experiment never exceeded 3 ml, the maximum decrease would be only 10 cm which means that the applied water should then theoretically reach 50 cm after redistribution. However after 15 hr from the fourth application of water, the K concentration of the soil solution at 50 cm depth was just slightly over the initial K concentration while the K concentration at 40 cm depth was highest. This would indicate that K was being held back. Potassium underwent ionic exchange spontaneously during flow of the solution through the column.

Using the second column and after continuous application of 15 cm of water, the concentrations of K, Ca, and Mg in the soil solution and water content at different depths following redistribution of the applied water are given in Table 55. The maximum K concentration in the soil

Table 55. Soil water tension (h), water content (θ) and K, Ca, and Mg contents of the soil solution at different depths before and 9.5 hr after 15 cm of continuous application of water.

| Depth | Before | | After 9.5 hr | | | | |
|--------|--------|----------|--------------|----------|-------|-------|-------|
| | h | θ | h | θ | K | Ca | Mg |
| cm | cm | % | cm | % | ----- | ppm | ----- |
| 0-10 | 105 | 15 | 44 | 36 | 6.3 | 5.2 | 2.0 |
| 10-20 | 91 | 15 | 48 | 28 | 7.6 | 8.0 | 1.3 |
| 20-30 | 80 | 16 | 53 | 24 | 14.2 | 13.0 | 2.7 |
| 30-40 | 70 | 16 | 59 | 20 | 55.0 | 27.0 | 3.1 |
| 40-50 | 60 | 20 | 48 | 25 | 212.5 | 235.0 | 21.5 |
| 50-60 | 50 | 26 | 41 | 31 | 1.0 | 52.0 | 10.2 |
| 60-70 | 40 | 37 | 32 | 38 | 0.3 | 30.5 | 4.3 |
| 70-80 | 30 | 34 | 23 | 35 | 0.2 | 16.8 | 2.5 |
| 80-90 | 19 | 39 | 14 | 39 | 0.2 | 12.3 | 1.7 |
| 90-100 | 9 | 32 | 6 | 32 | 1.0 | 9.3 | 1.1 |

solution was at 50 cm depth and the concentration decreased gradually towards the surface of the column. If the rate of water application was sufficient to saturate the soil surface and flow occurred under water-saturated conditions according to the saturated water contents (Table 46), then 40 cm would be the theoretical depth reached with the application of 15 cm of water. In reality, this is not expected since, unless there is a layer below the soil surface with physical properties that may restrict water movement, the surface soil will not saturate with 2.5 cm/hr rate of water application because saturated hydraulic conductivity is 19 cm/hr. In the experiment, the surface soil actually never became saturated since water application rate was much less than the hydraulic conductivity at about -45 cm of water tension of the soil. The data indicate that at the end of the water application period, the highest K concentration in the soil solution was at 50 cm depth. Undoubtedly, flow was taking place under unsaturated conditions and apparently, the highest concentration of K was in the advancing bulk solution. During the redistribution of water to approach the initial water content, K moved with water to lower depths in the column. The tailing of K concentration towards the surface may be due to either incomplete dissolution of KCl or dilution.

Although no data on Ca and Mg concentrations were obtained prior to application of water, it appears that Ca and Mg were being pushed down with the displaced solution. Since no Ca or Mg was applied to the column, this data suggest that movement of Ca and Mg in the column was a result of replacement on the soil exchange sites by K. The high K concentration in the solution in dynamic equilibrium with the soil probably resulted in greater adsorption of K by the soil and consequently, greater replacement of Ca and Mg by mass action. In contrast, the low K concentrations

(90 ppm K) of solutions used in the Q/I relation study resulted in lower K adsorption.

During miscible displacement of one fluid by another, solute diffusion across the boundary results in the disappearance of the initially sharp boundary between the two fluids. The variation in microscopic velocities of fluid during miscible displacement also causes dispersion of the solute in the displacing fluid. Therefore, solute dispersion primarily results from either molecular diffusion or fluid dispersion or both.

Laboratory procedures for studying solute dispersion under saturated condition usually involve saturating a column of soil with a solution and displacing it with another solution containing the solute being studied. The change in solute concentration (C) of the effluent is plotted against the volume of effluent collected at one end of the column. A breakthrough curve is normally obtained by a plot of the dimensionless ratio C/C_0 (relative concentration) against the number of pore volumes, V/V_0 , of effluent collected, where C_0 is the initial concentration of the solute in the solution prior to displacement, V is the volume of effluent, and V_0 is the effective pore volume. Theoretically, if no fluid mixing occurs (such as in a water pipe), the breakthrough curve will be that of a piston flow, i. e., when one pore volume of effluent has been collected the solute concentration in the effluent will abruptly change to that of the displacing liquid ($C/C_0=1$). Experimental breakthrough curves for porous media, however, usually show a gradual increase followed by a decrease in concentration of the solute in the effluent as the displacing fluid passes through the column. Equations for one-dimensional dispersion of an inert solute (such as Cl^-) dictate that when one pore volume has

passed through the column, C/C_0 should be equal to 0.5. The position as well as the shape of the breakthrough curve for certain solutions with reference to this point characterizes solute dispersion with regard to adsorption in the soil. Adsorption of the solute causes a delay in the breakthrough, i. e., the curve will appear to the right of the theoretical point ($C/C_0=0.5$). Desorption of the solute may result in extensive tailing of a breakthrough curve. Repulsion of the solute by the soil causes an advanced appearance of the breakthrough curve.

The experimental breakthrough curves for K and Cl^- in Lakeland fine sand are shown in Figures 5 to 8. The Cl^- concentrations in the effluent fractions were based on Cl^{36} activity. The curves for K were always to the right of Cl^- curve. It appears that Cl^- may have been adsorbed by the soil but to a lesser extent than K. Under saturated conditions (Figures 5 to 7), the effect of increasing flow velocity from 18 to 22 cm/hr was to cause the K breakthrough curve to appear earlier at the faster flow rate than at the lower flow rate. This is probably an effect of pushing the solution through the larger pores faster. Also, the peak of the K breakthrough curve decreased with increased flow velocity while that of Cl^- did not change. There was no difference in the breakthrough curves between flow velocities of 22 and 69 cm/hr except that the peak of K breakthrough curve was slightly lower at the higher flow velocity than at the lower flow velocity. The breakthrough curves for unsaturated conditions (Figure 8) show an increased delay of K breakthrough with reference to Cl^- and to the reference point ($C/C_0=0.5$). It appears that Cl^- is being repelled by the soil since the Cl^- breakthrough curve appeared earlier relative to the theoretical point.

Desaturation changes the pattern of flow of the solution through the

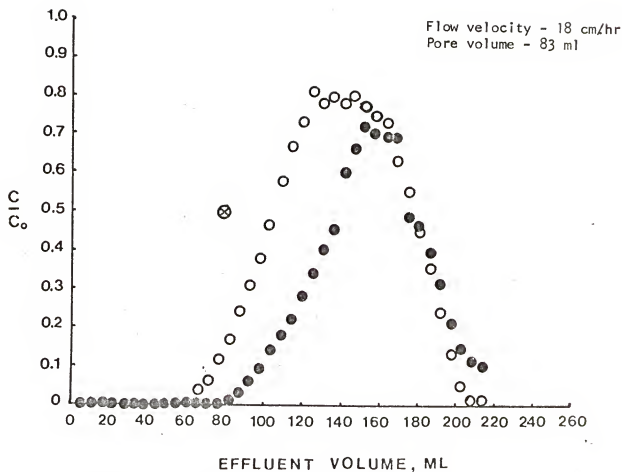


Figure 5. Breakthrough curves of K (●) and Cl^- (○) under saturated condition at flow velocity of 18 cm/hr.

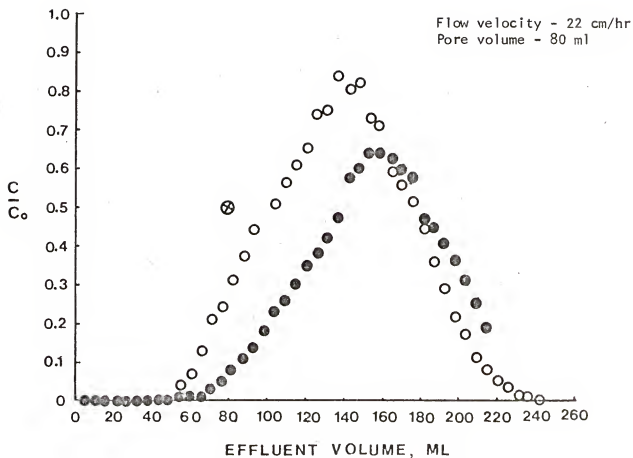


Figure 6. Breakthrough curves of K (●) and Cl⁻ (○) under saturated condition at flow velocity of 22 cm/hr.

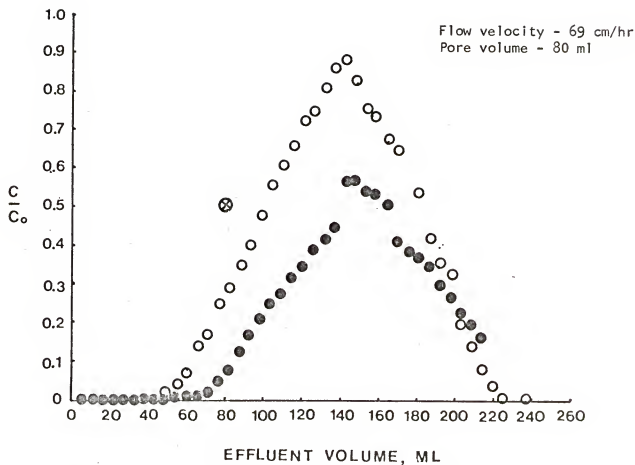


Figure 7. Breakthrough curves of K (●) and Cl⁻ (○) under saturated condition at flow velocity of 69 cm/hr.

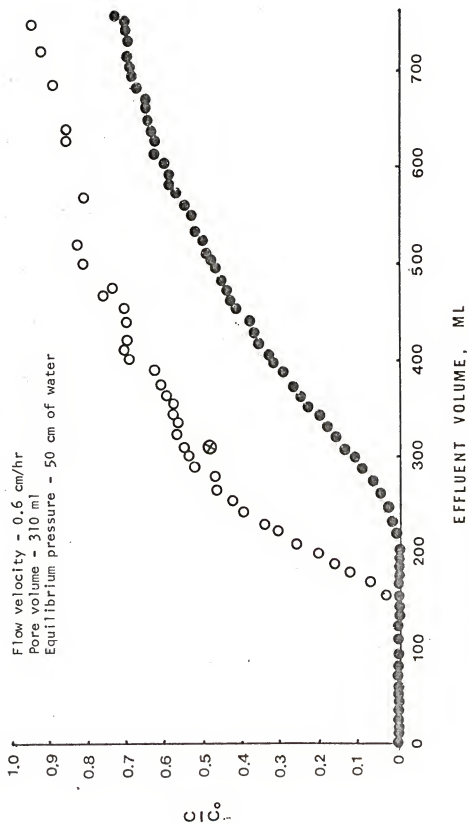


Figure 8. Breakthrough curves of K (●) and Cl^- (○) under unsaturated condition.

soil. The contribution of the larger pores to the flow diminishes as the water content decreases while the smaller pores increase their importance. Consequently, the flow path becomes more tortuous and the proportion of the solution in contact with the soil particles participating in ion exchange increases.

The delay in the breakthrough of K both under saturated and unsaturated conditions can be attributed to adsorption of K on the soil exchange complex. The increased delay for the unsaturated flow was probably due to greater K adsorption than for the saturated flow. The slower velocity of flow under unsaturated conditions allows completion of ion exchange between soil and solution.

SUMMARY AND CONCLUSIONS

Two field experiments were conducted to study K movement from soluble and slowly soluble K fertilizers and its effect on yield and composition of flue-cured tobacco.

In the 1972 experiment, the main treatments consisted of the tobacco-grade fertilizer (4-3.5-10) applied split or once; compounded 4-3.5-10 with K supplied as sulfur-coated K_2SO_4 (termed SCK) with 36% coating or with 18% coating, and as uncoated granular K_2SO_4 ; and resin-coated 7-6-17.5 (Osmocote). Subtreatments were three rates equivalent to 450, 900, and 1800 kg/ha of 4-3.5-10. In addition, a treatment with no K (4-3.5-0) and a treatment using Osmocote 7-6-17.5 with all N applied at planting were studied. The main treatments did not significantly affect yields, total alkaloid contents and reducing sugar contents of the leaves. The K contents of the leaves were higher for tobacco-grade 4-3.5-10 applied split, Osmocote 7-6-17.5, and with granular K_2SO_4 than the remaining treatments. The K content of the soil samples collected at different depths varied significantly among treatments but the effect of treatments was independent of sampling. The soil samples from plots treated with tobacco-grade 4-3.5-10 applied split and Osmocote 7-6-17.5 contained significantly less K than plots treated with granular K_2SO_4 . Data on K uptake could not explain the differences in the K contents of the soil and there was no significant treatment x depth interaction effect. The data indicated greater movement of K from soluble K fertilizers to lower depths than from the slowly soluble K fertilizers. Because of the relatively high rates and low rainfall during the experiment, treatments did not affect yield or

composition of flue-cured tobacco.

In the 1973 experiment, the main treatments consisted of the tobacco-grade 4-3.5-10 applied split, Swift product 0-6.5-25 with N supplied either from IBDU or NH_4NO_3 , compounded 4-3.5-10 with K supplied as SCK (26% coating), Osmocote 7-6-17.5, and 4-3.5-0. Subtreatments were three rates similar to the 1972 experiment. The Swift product, SCK, and Osmocote were the three slowly soluble K fertilizers in the study. Yields of flue-cured tobacco varied among fertilizer treatments in two out of five primings as well as the total of the five priming yields. Higher total yields were obtained from the slowly soluble K fertilizers than the soluble one. The K contents of the leaves varied significantly in the first, second, and fifth priming. The slowly soluble K fertilizers, except where IBDU was applied, generally increased K contents of the leaves and K uptake. Where no K was applied, the K contents of the leaves did not appreciably differ from those where K was applied. The very wet condition in the 1973 experiment may have moved K laterally and affected the no-K treated plots in the experimental area. Total alkaloid content of the leaves increased with rate while reducing sugar content decreased with rate of fertilizer applied. The effect of treatments on total reducing sugar contents seemed to be more associated with N availability than K. There were differences in the value of flue-cured tobacco but the differences did not indicate any advantage of the slowly soluble K fertilizers over the tobacco-grade fertilizer. The K contents of the soil were lower than those in the 1972 experiment. The K from the slowly soluble K fertilizers did not seem to move down in the soil as quickly as the tobacco-grade fertilizer possibly because they did not dissolve as readily.

Field and laboratory experiments were conducted to study effect of water movement on K movement in the soil. In the field, results showed that intermittent application of water totalling 11.18 cm did not move K from a soluble fertilizer (7-6-17.5) lower than about 15 cm in the profile. With continuous application of 15 cm of water, the K from soluble fertilizer moved down to as far as 75 cm while most K from slowly soluble form of 7-6-17.5 was still in the upper 45-cm depth. The results from laboratory studies suggested that K was lagging behind the water moving downward possibly due to adsorption by the soil. This observation was supported by the data from miscible displacement studies for K and Cl^- under saturated and unsaturated condition.

LITERATURE CITED

- Adams, F. and Z. F. Lund. 1966. Effect of chemical activity of soil solution aluminum on cotton root penetration of acid subsoils. *Soil Sci.* 101:193-198.
- Adams, W. E., A. W. White, K. A. McCreery, and R. N. Dawson. 1967. Coastal bermudagrass forage production and chemical composition as influenced by potassium source, rate, and frequency of application. *Agron. J.* 59:247-250.
- Allison, L. E. 1965. Organic carbon. *In* C. A. Black (ed.) *Methods of Soil Analysis. Part II: Chemical and Microbiological Properties.* Agronomy 9:1367-1378. Amer. Soc. of Agron., Madison, Wis.
- Ayres, A. S. and H. H. Hagiwara. 1953. Effect of the anion on the sorption of potassium by some humic and hydrol humic latosols. *Soil Sci.* 75:1-17.
- Barber, S. S. 1962. A diffusion and mass-flow concept of soil nutrient availability. *Soil Sci.* 93:39-49.
- Barber, S. A., J. M. Walker, and E. H. Vasey. 1963. Mechanisms for the movement of plant nutrients from the soil and fertilizer to the plant root. *J. Agr. Food Chem.* 11:204-207.
- Bartlett, R. J. and J. L. McIntosh. 1969. pH-dependent bonding of potassium by a spodosol. *Soil Sci. Soc. Amer. Proc.* 33:535-539.
- Baver, L. D., W. H. Gardner, and W. R. Gardner. 1972. *Soil Physics.* John Wiley & Sons, Inc., New York.
- Beckett, P. H. T. 1964. Studies on soil potassium I: Confirmation of the ratio law and measurement of potassium potential. *J. Soil Sci.* 15:1-8.
- Beckett, P. H. T. 1967. Potassium potential. *In* *Soil Potassium and Magnesium. Proceedings of a conference organized by the soil chemists of the National Agricultural Advisory Service.* Ministry of Agriculture, Fisheries and Food Technical Bul. No. 14, p. 32-38, London.
- Beckett, P. H. T. 1972. Critical cation activity ratio. *Advance. Agron.* 24:379-412.
- Biggar, J. W. and D. R. Nielsen. 1967. Miscible displacement and leaching phenomenon. *In* R. M. Hagan, H. R. Haise, and T. W. Edminster (ed.) *Irrigation of Agricultural Lands.* Agronomy 11:254-274. Amer. Soc. of Agron., Madison, Wis.

Boast, C. W. 1973. Modelling the movement of chemicals in soil by water. *Soil Sci.* 115:224-230.

Bresler, E. and R. J. Hanks. 1969. Numerical methods for estimating simultaneous flow of water and salt in unsaturated soils. *Soil Sci. Soc. Amer. Proc.* 33:827-832.

Caldwell, A. C. and J. R. Kline. 1963. Effect of variously soluble potassium fertilizers on yield and composition of some crop plants. *Agron. J.* 55:542-545.

Chandler, R. F., Jr., and R. B. Musgrave. 1944. A comparison of potassium chloride and potassium metaphosphate as source of potassium for plants. *Soil Sci. Soc. Amer. Proc.* 9:151-153.

Day, P. R. 1956. Dispersion of moving salt-water boundary advancing through saturated sand. *Trans. Am. Geophys. Union* 37:595-601.

DeMent, J. D. and G. Stanford. 1959. Potassium availability of fused potassium phosphates. *Agron. J.* 51:282-285.

DeMent, J. D., G. L. Terman, and B. N. Bradford. 1963. Crop response to phosphorus and potassium in potassium phosphate varying widely in particle size. *Jour. Agr. Food Chem.* 11:207-212.

Drew, M. C., L. V. Vaidyanathan, and P. H. Nye. 1967. Can soil diffusion limit the uptake of potassium by plants? *Trans. Intl. Soil Sci. Soc. Commission II and IV. Soil Chemistry and Fertility.* p. 335-344.

Engelstad, O. P. 1968. Agronomic evaluation of potassium polyphosphate and potassium calcium pyrophosphate as source of potassium. *In* V. J. Kilmer, S. E. Younts, and N. C. Brady (ed.) *The Role of Potassium in Agriculture.* p. 63-77. Amer. Soc. of Agron., Madison, Wis.

Fiskell, J. G. A. 1970. Cation-exchange capacity and component variations of soils of southeastern U. S. A. *Soil Sci. Soc. Amer. Proc.* 34:723-727.

Fiskell, J. G. A., N. Gammon, Jr., T. L. Yuan, and O. Zmeskal. 1958. Colloidal properties of some Florida soils. *Soil Sci. Soc. Amer. Proc.* 22:339-343.

Fiskell, J. G. A. and S. B. McCaleb. 1953. Nature of the clay fractions of some soils in Florida. *Soil Sci.* 76:431-446.

Fiskell, J. G. A. and L. W. Zelazny. 1971. Acidic properties of some Florida soils I. pH-dependent cation exchange. *Soil and Crop Sci. Soc. Fla. Proc.* 31:145-149.

Fried, M. and H. Broeshart. 1967. *The Soil-Plant System.* Academic Press, New York.

- Gammon, N., Jr. 1957. The behavior of potassium and potassium fertilizers in Florida soils. *Soil and Crop Sci. Soc. Fla. Proc.* 17: 156-160.
- Gammon, N., Jr., J. R. Henderson, R. A. Carrigan, R. E. Caldwell, R. G. Leighty, and F. B. Smith. 1953. Physical, spectrographic, and chemical analyses of some virgin Florida soils. *Univ. of Florida Agr. Exp. Sta. Tech. Bul.* 524.
- Graham, E. R. and R. L. Fox. 1971. Tropical soil potassium as related to labile pool and calcium exchange equilibria. *Soil Sci.* 111:318-322.
- Gree, R. E. and J. C. Corey. 1971. Calculation of hydraulic conductivity: A further evaluation of some predictive methods. *Soil Sci. Soc. Amer. Proc.* 35:3-8.
- Hagin, J. 1966. Evaluation of potassium metaphosphate as fertilizer. *Soil Sci.* 40:145-168.
- Hall, N. S., W. K. Chandler, C. H. M. van Bavel, P. H. Reid, and J. H. Anderson. 1953. Tracer technique to measure growth and activity of plant root system. *North Carolina Agr. Exp. Sta. Tech. Bul. No.* 101.
- Hammond, L. C., H. W. Lundy, and G. K. Saxena. 1967. Influence of underground asphalt barriers on water retention and movement in Lakeland fine sand. *Soil and Crop Sci. Soc. Fla. Proc.* 27:11-19.
- Hawks, S. N. 1970. *Principles of Flue-Cured Tobacco Production.* North Carolina State University.
- Hawks, S. N., D. L. Terry, and W. K. Collins. 1973. Effect of potassium and magnesium at three rates on yield and price of flue-cured tobacco. *Tobacco Sci.* 17:74-75.
- Hauck, R. D. and M. Koshino. 1971. Slow-release and amended fertilizers. In R. A. Olson, T. J. Army, J. J. Hanway, and V. J. Kilmer (ed.) *Fertilizer Technology & Use.* p. 455-494. *Soil Sci. Soc. Amer., Inc.* Madison, Wis.
- Howard, D. D. and F. Adams. 1965. Calcium requirements of penetration of subsoils by primary cotton roots. *Soil Sci. Soc. Amer. Proc.* 29: 558-562.
- Jackson, W. A. and R. S. Volk. 1968. Role of potassium in photosynthesis and respiration. In V. J. Kilmer, S. E. Younts, and N. C. Brady (ed.) *The Role of Potassium in Agriculture.* p. 109-145. *Amer. Soc. of Agron.,* Madison, Wis.
- Lawton, K. 1961. The effect of coatings on the dissolution of fertilizers and the uptake of fertilizer potassium by plants. *J. Agr. Food Chem.* 9: 276-280.

- Lai, S.-H. and J. J. Jurinak. 1972. Cation adsorption in one-dimensional flow through soils: A numerical solution. *Water Resour. Res.* 8:99-107.
- Liebhardt, W. C. 1968. Effect of potassium in carbohydrate metabolism and translocation. In V. J. Kilmer, S. E. Younts, and N. C. Brady (ed.) *The Role of Potassium in Agriculture*. p. 147-164. Amer. Soc. of Agron., Madison, Wis.
- Lutrick, M. C. 1958. The downward movement of potassium in Eustis loamy fine sand. *Soil and Crop Sci. Soc. Fla. Proc.* 18:198-202.
- McCants, C. B. and W. G. Woltz. 1967. Growth and mineral nutrition of tobacco. *Advance. Agron.* 19:211-265.
- McLean, E. O. and E. J. Owen. 1969. Effects of pH on the contributions of organic matter and clay to soil cation exchange capacities. *Soil Sci. Soc. Amer. Proc.* 33:855-858.
- Mekaru, T. and G. Uehara. 1972. Anion adsorption in Ferruginous tropical soils. *Soil Sci. Soc. Amer. Proc.* 36:296-300.
- Miller, R. J., J. W. Biggar, and D. R. Nielsen. 1965. Chloride displacement in Panoche clay loam in relation to water movement and distribution. *Water Resour. Res.* 1:63-71.
- Miller, E. E. and A. Klute. 1967. The dynamics of soil water. Part I. Mechanical forces. In R. M. Hagan, H. R. Haise, and T. W. Edminster (ed.) *Irrigation of Agricultural Lands*. Agronomy 11:209-244. Amer. Soc. of Agron., Madison, Wis.
- Mortland, M. M., K. Lawton, and G. Uehara. 1957. Fixation and release of K by some clay minerals. *Soil Sci. Soc. Amer. Proc.* 21:381-384.
- Murdock, L. W. and C. I. Rich. 1965. Potassium availability in Nason soils as influenced by ammonium and lime. *Soil Sci. Soc. Amer. Proc.* 29:707-711.
- Nakano, Y. and R. P. Murrmann. 1971. A statistical method for analysis of diffusion in soils. *Soil Sci. Soc. Amer. Proc.* 35:397-402.
- Nelson, N. T. and E. T. McEvoy. 1945. The use of potash in tobacco production. *Lighter* 15:12-15.
- Nolan, C. N. and W. L. Pritchett. 1960. Certain factors affecting the leaching of potassium from sandy soils. *Soil and Crop Sci. Soc. Fla. Proc.* 20:139-145.
- Peech, M. and R. Bradfield. 1943. The effect of lime and magnesia on the soil potassium and on the absorption of potassium by plants. *Soil Sci.* 55:37-48.
- Rible, J. M. and L. E. Davis. 1955. Ion exchange in soil columns. *Soil Sci.* 79:41-47.

San Valentin, G. O., W. K. Robertson, and H. W. Lundy. 1971. Slowly soluble potassium fertilizers as potassium sources for tobacco on sandy soils. *Soil and Crop Sci. Soc. Fla. Proc.* 31:87-91.

Spencer, W. F. 1954. Influence of cation-exchange reaction on retention and availability of cations on sandy soils. *Soil Sci.* 77:129-136.

Stanford, G. 1947. Fixation of potassium in soils under moist conditions and on drying in relation to type of clay minerals. *Soil Sci. Soc. Amer. Proc.* 12:167-171.

Teel, M. R. 1968. The effect of potassium on the organic acid and nonprotein nitrogen content of plant tissue. *In* V. J. Kilmer, S. E. Younts, and N. C. Brady (ed.) *The Role of Potassium in Agriculture*. p. 165-188. Amer. Soc. of Agron., Madison, Wis.

Thomas, G. W. and N. T. Coleman. 1959. A chromatographic approach to leaching of fertilizer salts in soils. *Soil Sci. Soc. Amer. Proc.* 23: 113-116.

van Reeuwijk, L. P. and J. M. de Villiers. 1968. Potassium fixation by amorphous aluminosilica gels. *Soil Sci. Soc. Amer. Proc.* 32:238-240.

Volk, G. M. and C. E. Bell. 1945. Some major factors on the leaching of calcium, potassium, sulfur, and nitrogen from sandy soils. *Florida Agr. Exp. Sta. Bul.* 416.

Warrick, A. W., J. W. Biggar, and D. R. Nielsen. 1971. Simultaneous solute and water transfer for an unsaturated soil. *Water Resour. Res.* 7:1216-1225.

Wild, A., D. G. Rowell, and M. A. Ogunfowora. 1969. The activity ratio as a measure of the intensity factor in potassium supply to plants. *Soil Sci.* 108:432-439.

Wilson, R. H. and H. S. Evans. 1968. The effect of potassium and other univalent cations on the conformation of enzymes. *In* V. J. Kilmer, S. E. Younts, and N. C. Brady (ed.) *The Role of Potassium in Agriculture*. p. 189-202. Amer. Soc. of Agron., Madison, Wis.

Woltz, W. G., W. A. Reid, W. E. Colwell. 1948. Sugar and nicotine in bright tobacco as related to mineral element composition. *Soil Sci. Soc. Amer. Proc.* 13:385-387.

Zelazny, L. W. and J. G. A. Fiskell. 1971. Acidic properties of some Florida soils. II. Exchangeable and titratable acidity. *Soil and Crop Sci. Soc. Fla. Proc.* 31:149-154.

BIOGRAPHICAL SKETCH

Genaro O. San Valentin was born on January 15, 1944, in Los Banos, Laguna, Philippines. He pursued his elementary education at Los Banos Elementary School and graduated from the Los Banos High School in April 1960. He received his degree of Bachelor of Science in Agriculture with a major in soils from the University of the Philippines in May 1965.

From June 1965 until August 1968, he worked in the soil physics laboratory of the Department of Soils, University of the Philippines. In September 1968 he joined the staff of Agricultural Sciences Department of the Philippine Atomic Energy Commission.

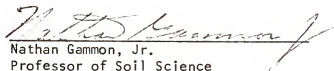
In September 1970, he was granted an International Atomic Energy Agency (IAEA) fellowship on which he has pursued graduate studies in soil science. In December 1971 he finished his Master of Science in Agriculture from the University of Florida. The IAEA fellowship also allowed him to continue his graduate studies leading to a Ph. D. degree until September 1972 when he was awarded a graduate assistantship by the Department of Soils, University of Florida.

I certify that I have read this study and that in my opinion it conforms to acceptable standard of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.




William K. Robertson, Chairman
Professor of Soil Science

I certify that I have read this study and that in my opinion it conforms to acceptable standard of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.




Nathan Gammon, Jr.
Professor of Soil Science

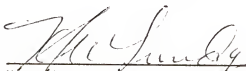
I certify that I have read this study and that in my opinion it conforms to acceptable standard of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.


Robert S. Mansell
Associate Professor of Soil Science

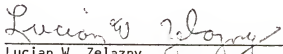
I certify that I have read this study and that in my opinion it conforms to acceptable standard of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.


Wallace S. Brey, Jr.
Professor of Chemistry

I certify that I have read this study and that in my opinion it conforms to acceptable standard of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.



Hosea W. Lundy
Associate Professor

I certify that I have read this study and that in my opinion it conforms to acceptable standard of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.


Lucian W. Zelazny
Assistant Professor of Soil Science

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

June, 1974


Dean, College of Agriculture

Dean, Graduate School